NURUL FAUZANA BT IMRAN GULCHARAN B. ENG. (HONS) ELECTRICAL & ELECTRONICS ENGINEERING MAY 2012

DEVELOPMENT & PERFORMANCE EVALUATION OF HYBRID NN – PID CONTROLLER FOR DC SERVOMOTOR

NURUL FAUZANA BINTI IMRAN GULCHARAN

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UNIVERSITI TEKNOLOGI PETRONAS
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By

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FINAL REPORT

Dissertation submitted to the Department of Electrical & Electronic Engineering
in partial fulfillment of the requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical and Electronic Engineering)

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Approved by,

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Dr. Rosdiazli Bin Ibrahim

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

May 2012

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained here have not been undertaken or done by unspecified sources or persons.

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Nurul Fauzana Binti Imran Gulcharan

ABSTRACT

The project focuses on position control of the DC Servo Motor MS150 Servomotor Modular. The objectives of the project is to design and develop an advanced control strategy for the use in the servomotor as well as to observe, evaluate and compare the controller performances of a proposed advanced controller – Artificial Neural Network (ANN) with the conventional controller that is Proportional – Integral – Derivative (PID) Control. This approach is selected to investigate and evaluate the conventional method in controlling the position of DC servomotor due to the advantage of cost reduction, simplicity, flexibility and also provides better performance. Based on the information obtained from servomotor modular, the controllers are designed and simulated using MATLAB/SIMULINK to analyze their initial performance. Finally, the performance of the controllers are compared and evaluated and the validation is done in terms of time response, overshoot response and steady – state error.

ACKNOWLEDGEMENT

First and foremost I would like to praise and thank Allah S.W.T for the strength, patience, guidance and opportunity He has provided me throughout my Final Year Project.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATION

ANN	=	Artificial Neural Network
CV	=	Control Variable
D	=	Derivative
DC	=	Direct Current
EMF	=	Electromagnetic Force
FYP	=	Final Year Project
HL	=	Hidden Layer
HLNet	=	Hidden Layer Network
I	=	Integral
K_d	=	Derivative gain
K_i	=	Integral gain
K_p	=	Proportional gain
KVL	=	Kirchhoff's Voltage Law
MLP	=	Multi Layer Perceptron
NN	=	Neural Network
NNet	=	Neural Network
P	=	Proportional
PID	=	Proportional – Integral – Derivative
PV	=	Process Variable
SP	=	Set Point
SSE	=	Steady – State Error
T.F	=	Transfer Function
Z – N	=	Ziegler – Nichols

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Proportional – Integral – Derivative (PID) has been used widely in control system as a part of the industrial process controls. The controller has been used throughout these years even with the advanced approaches that has been introduced recently is due to its robustness. However, the only setback that the PID produces is through its adjustment of the three gains where is needs to be in a proper value or the whole system might not produce the desired performance it needed.

The Neural Controllers proposed recently has opened a door in order to help the PID controller to have a proper or better performance in its system. However, the ANN controller needs to learn the plant behavior before it can actually help in controlling the actual plant.

The project focuses on position control of DC servomotor. The main objective is to design and develop an advanced control strategy for the control of a DC Servomotor, where Artificial Neural Network (ANN) and conventional controller PID controllers' design approaches is applied. The advanced controller is selected to help the conventional method in producing better performance by designing a hybrid controller based on the PID controller performances and ANN controller that has been trained using the off – line test data set obtained from the model of non – linear plant which in this case is the MS150 Servomotor Modular.

1.2 Problem Statement

Although the Direct Current (DC) Servomotor is highly used in the control system area, the servomotor also serves its limitations during application whereby generally the efficiency and losses are hard to predict in terms of stabilization. This is where a method of “tuning” is required to stabilize its feedback loop.

The second issue that is highlighted in the research is regarding the conventional controller (PID). Although PID is a widely used controller for a feedback loop application, PID controller provides inconsistency of performance due to the controller is based on linear control theory. The fundamental difficulty of PID control is that it is a feedback system which consists of constant parameters (K_p, K_i, K_d) and has no direct knowledge of process thus leading to a reactive and compromised performance. The controller uses a longer period of time in tuning in order to obtain wanted results. The stability of the performance is also at stake if the parameters are not tuned properly.

1.3 Objectives

1. To design and develop an advanced control strategy for the use in servo motor.
2. To observe, evaluate and compare the control performance of the proposed controllers (ANN) and conventional controller (PID Controller)

1.4 Scope of Study

For this project, the scope of study will be focus on finding the most suitable controller or approach to develop the control strategy and also in searching of the right platform for development phase. The scope is to investigate the ANN control performances by comparison to PID in terms of overshoot response, time response and percentage of error. The information of the servomotor’s the transfer function and other general information is obtained from the MS150 Servomotor Modular. The simulation and results for this project are being simulated by MATLAB/SIMULINK software.

1.5 Relevancy of Project

This project aim is to overcome the difficulty of obtaining stabilized performance as well as providing the more efficient controller for the servo system. By comparing the control performances, the investigation in NN method would provide potential solution in achieving better performances of the servomotor. The research also could provide a better understanding on applying the method on any future hybrid controller. In terms of study area, servo motor is applicable in numerous areas involving control system such as manufacturing industry, transportation, plantation or even military.

1.6 Feasibility of Project

1.6.1 Technical feasibility

Technical feasibility is defined by technical aspects taken into consideration and also the determination of sensibility and practicality of the whole application.

1.6.1.1 Familiarity of the technology

A basic need of fundamental knowledge for each technology used that is the controllers' technology and DC MS150 Servomotor Modular technology in order to obtain enough information on requirements of applications.

1.6.1.2 Compatibility of application

The software that is used for is MATLAB. It is compatible software which can be used to implement the controller simulation.

1.6.2 Feasibility within scope and time frame

Since this is a simulation based research, looking on the economical or cost efficiency of this project, the project is feasible due to the software for simulation can be downloaded and could be used within own time frame and space.

CHAPTER 2

LITERATURE REVIEW

2.0 Servo System

2.0.1 Servomechanism

Servomechanism or servo is defined in short as an automatic device. The device uses error – sensing negative feedback to obtain the right performance of a mechanism that would help to control the mechanical position, speed or other parameters applied. Servos are commonly known to be electrically and partially electronic in nature that uses electrical motor as a main aspect to produce mechanical force [1]. A motor which forms a part of servomechanism that is paired together with a type of encoder that enables feedback of position or speed to be applied or provided.

A servo has two (2) aspects which are position and speed control. Position control is when the servo operates on the principle of negative feedback. The control input is compared to the actual position of the mechanical system. The difference obtained between actual and wanted values are known as error signals. The error signals are then amplified and used to drive the system in a direction to reduce or eliminate the error [1].

Temiz and Akar (2007) from their paper, DC servomotor has wide range of uses in different technology categories such as industrial equipment, weapon industry and speed control of alternators, and control mechanism of full automatic regulators [2].

2.0.2 Direct Current (DC) Servo Motor

DC Servomotor is an assembly of three (3) items which are a gear reduction unit, a position – sensing device and a control circuit. The function of the servo is to receive a control signal (desired output position) and power is applied to the DC motor turn the shaft to the wanted position. The position – sensing device is used to determine the shaft rotational position. The shaft of the servo does not typically rotates freely at 360 degree unless it is uncontrollable but can only turn at a maximum of 180 degrees or less back and forth.

The input and output of a servomotor is the voltage value and angular position accordingly. From Laubwald E. (n.d) states that the basic form of a DC Servo System is made of an electric motor with an output shaft that has an inertial load *J*, and friction in the bearings of the motor and loads which is denoted by constant *b*. An electric drive circuit, an input voltage *u(t)* is transformed by the motor into a torque *T(t)* in the motor output shaft [3].

A DC servomotor holds advantages for its application where it has the motor size and weight, higher efficiency, higher torque to inertia ratio, able to accelerate loads fast, usable at high speed torque and is also audibly quiet at high speed [4].

2.0.3 Derivation of DC Servo Motor Transfer Function

The derivation of Transfer Function (T.F) in a DC Motor is divided into three (3) major components of equation which are: electrical equation, mechanical equation and electro – mechanical equation [5].

For the electrical equation is obtained by applying the Kirchhoff's Voltage Law (KVL) where;

$$v_a(t) - v_b(t) = L\,\frac{\partial i_a(t)}{\partial t} + R\,i_a(t) \qquad (2.1)$$

The mechanical equation is based on the Newton Law of Motion, described by;

$$T_m(t) = J\frac{\partial^2 \theta_m(t)}{\partial t^2} + B\,\frac{\partial \theta_m(t)}{\partial t} \qquad (2.2)$$

When the input voltage $v_a(t)$ is applied, the armature current i_a (t) goes through the resistance, R_a and inductance, L_a which then produces the magnetic flux $\emptyset$ causing the motion to the rotor according to the motor torque as illustrated in equation below;

$$T_m(t) = K_t i_a(t) \qquad (2.3)$$

The Back Electromagnetic Force (EMF) is induced by angular speed of motor shaft to obtain;

$$v_b(t) = K_b\omega_m(t) = K_b\,\frac{\partial \theta_m(t)}{\partial t} \qquad (2.4)$$

Substituting Equation 2.4 into Equation 2.1 and Equation 2.3 into Equation 2.2 obtaining for both equations;

$$V(t) = L\,\frac{\partial i_a(t)}{\partial t} + Ri_a(t) + K_b\frac{\partial \theta_m(t)}{\partial t} \qquad (2.5),$$

and,

$$K_t i_a(t) = J\frac{\partial^2 \theta_m(t)}{\partial t^2} + B\frac{\partial \theta_m(t)}{\partial t} \qquad (2.6)$$

The two equations before (2.5 and 2.6) are then been transformed using the Laplace Transform method to obtain;

$$V(s) = sLI_a(s) + RI_a(s) + sK_b\theta_m(s) \qquad (2.7),$$

and

$$K_t I_a(s) = Js^2\theta_m(s) + sB\theta_m(s) \qquad (2.8)$$

Substituting the Equation 2.7 and Equation 2.8 into the motor speed T.F obtaining;

$$G_{speed}\,(s) = \frac{\Omega_m(s)}{V_a(s)} = \frac{K_t}{JL\,s^2+(JR+BL)s+BR+K_t+K_b} \qquad (2.9)$$

It is said to be that position control is time integral of speed. The T.F of position control can be obtained by multiplying the above equation with $\frac{1}{s}$ resulting in;

$$G_{position}\,(s) = \frac{\Omega_m(s)}{V_a(s)} = \frac{K_t}{s[JL\,s^2+(JR+BL)s+BR+K_t+K_b]} \qquad (2.10)$$

To obtain the full transfer function of the equation, parameters from the MS150 is being used in this study case. The parameters are shown in Table 2.1 below:

Table 2.1: Main Parameters of system MS150 [6]

PARAMETER	**VALUE**
Gain of IP/OP potentiometer	K_p = 4.8 V/rad
Gain of Tacho Generator	K_g = 0.025V/rad/s
Gain of Op – Amplifier	K_{op} = 10
Gain of Attenuator unit	K_{au} = 0.256
Gain of Pre – Amplifier	K_{pa} = 25
Gain of Servo Amplifier	K_{sa} = 2
Resistance of armature of motor	R= 3.2 Ω
Inductance of armature of motor	L = 8.6 x 10^{-3} H
Torque constant	K_t = 3.3 x 10^{-3} V/rad/s
Back EMF constant	K_b = 100 x 10^{-3} V/rad/s
Inertia at motor rotor	J_m= 30 x 10^{-6} kgm^2
Inertia of additional inertia disc	J_l = 412 x 10^{-6} kgm^2
Viscous friction coefficient of motor shaft	B_m = 50 x 10^{-6} Nt ms
Viscous friction coefficient of load shaft	B_l = 160 x 10^{-6} Nt ms

The study of DC Motor with no load is shown by substituting the above values into Equation 2.9;

$$G_{speed}\,(s) = \frac{\Omega_m(s)}{V_a(s)} = \frac{3300}{0.258s^2+96s+490} \qquad (2.11)$$

For armature – controlled DC Servomotors, closed loop TF of speed and position control can be derived as [5] [6];

$$H(s) = \frac{\theta_0(s)}{\theta_i(s)} = \frac{K_p K_s K_t}{RBs(1+\tau_a s)(1+\tau_s)+\left(K_t K_b + K_t K_s K_g\right)s + K_p K_s K_t} \quad (2.12)$$

Where;

$K_s = K_{op} K_{au} K_{pa} K_{sa}$ $\tau = J/B$

$\tau_a = L/R$ *(Negligible due to electrical time constant comparison to mechanical time constant)*

Hence, Equation 2.12 can be simplified as,

$$H(s) = \frac{\theta_o(s)}{\theta_i(s)} = \frac{K_p K_s K_t}{RJ s^2 + \left(RB + K_t K_b + K_t K_s K_g\right)s + K_p K_s K_t} \quad (2.13)$$

Substituting the values, the closed – loop transfer function for no load is defined as;

$$H(S) = \frac{\theta_o(s)}{\theta_i(s)} = \frac{21.12}{s^2+115.1s+21.12} \quad (2.14)$$

Meanwhile the TF of the plant is denoted by:

$$H_1(S) = \frac{\theta_o(s)}{\theta_i(s)} = \frac{2027520}{0.258s^3 + 96s + 11050s} \quad (2.15)$$

2.1 Controller

2.1.1 Proportional – Integral – Derivative (PID) Controller

The PID controller is a conventional controller which is widely used by numerous industries. This is due to the controller handler (engineer) only needed to determine by the best settings for three (3) actions which are the Proportional (P), Integral (I) and Derivative (D) in order to achieve the desired closed loop performance. A control variable (CV), output is based on error between user defined set point (SP) and measured process variable (PV) [8]. P, I and D are defined as per equation follow [18]:

$$u(t) = K_p . e(t) + K_i . \int e(t)dt + K_d . \frac{de(t)}{dt} \tag{2.16}$$

Where;
u(t) is the control
e(t) is the error signal
K_p *is the gain for proportional term,*
K_d *is the gain for derivative term and,*
K_i *is the gain for the integral term.*

Conventional PID is the most common controller used to control the servo system. It has a few advantages in terms of designing, low cost in maintenance and effectiveness. The mechanical – electrical model of the servo motor is presented in nonlinear model where at least one of the states is argumentable. The terms need to be linearized in order to be presented into a form of transfer function but however; nonlinearities are neglectable due to its small value [7].

Amongst all the tuning methods that have been used along with the PID controller, Ziegler – Nichols (Z-N) has been found the most popular and effective tuning method where it is divided into two (2) different methods; either open – loop method or closed – loop method. Closed – loop tuning method is used where it relies only on the parameters that were obtained from the plant step response. With this Z-N step response method is able to provide a systematic means to adjust the P gain in order to obtain no overshoot on the closed – loop step response [8].

However, a PID controller system serves its limitation where it does not guarantee optimal control or stability besides inconsistence performance [9]. The stability of the end performance is also at stake due to the period that the controller needed in order to obtain the right tuning parameters.

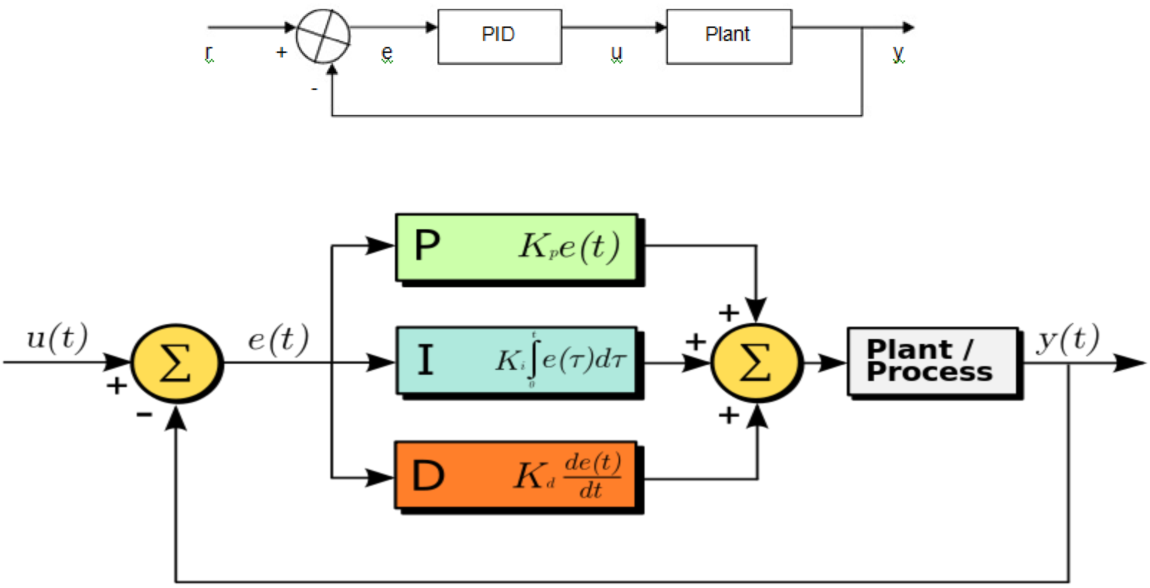


Figure 2.1: PID Controller

2.1.2 Neural Network (NN) Controller

High reliable performance controllers are needed nowadays to ensure the output of good dynamics performance in order to deal with the increment of complex environments. It is stated that the NN is well known to be biological system that would be able to perform complex routines without recourse to explicit quantitative operations [10].

This controller possesses self – learning capabilities, non – linear mapping and also fault tolerant architecture which will demonstrate or shown the ability to deal with the nonlinearities and time – varying parameters [12].

Quoted from Nguyen, Prasad and etc. (2003) in their book, a NN is said to be a collection of artificial neurons where it is a mathematical model of a biological neuron in its simplest form. Artificial NN (ANN) is mathematical models inspired from the individuals understanding of the biological nervous systems which are attractive as computation device which can accept large number of inputs and learn solely from training samples [10].

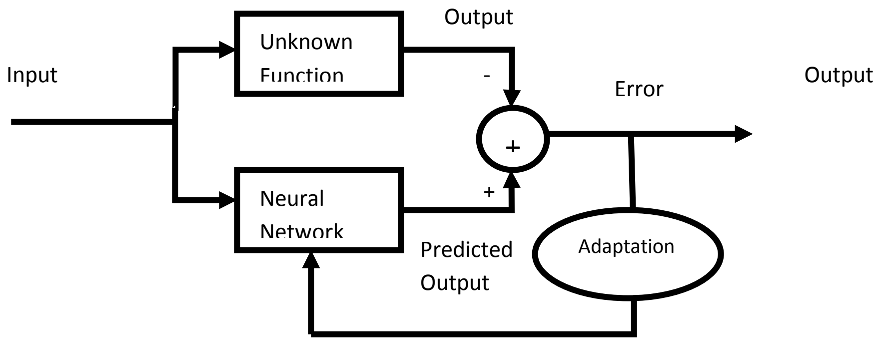


Figure 2.2: Neural Network as Function Approximator [11]

The ANN controller in control system is seen as a natural step in growing evolution to meet the need for a better control in the increasingly complex dynamical systems. The increment also has led to the increasing numbers of general concept of control which includes higher level of capabilities criteria which are decision making, planning and learning.

ANN is also said to offer new and promising direction towards better understanding, or even solving control problem difficulties. History has said that the NN controller is acceptable and usable when it is able to solve current problems which previously are either difficult or unsolvable [13].

In development of an ANN controller, there are usually four (4) phases are involved. These phases are (i) determine a controller structure which includes the topology of NN, (ii) requirement of plant knowledge to be used as training information, (iii) development of training scheme, and (iv) optimize the weights (tuning parameters) of NN in terms of training scheme to achieve the end results [12].

An ANN which has been trained possesses advantages over the classical techniques in terms of [14]:

i. Adaptive learning
ii. Self-organization
iii. Real time operation
iv. Fault tolerance via redundant information coding

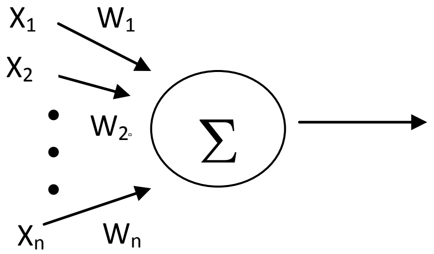
McCulloch and Pitts in [10] proposed the first computational model for artificial neural, where the outputs are binary, and the function is the step function represented by [10],

$$f(x) = \begin{cases} 1, & x \geq 0 \\ 0, & x < 0 \end{cases} \quad (2.17)$$

so that the activation of that neuron is represented by,

$$f\left(\sum_{i=1}^{n} w_i x_i - b\right) = \begin{cases} 1, & if \ \sum_{i=1}^{n} w_i x_i \geq b \\ 0, & if \ \sum_{i=1}^{n} w_i x_1 < b \end{cases} \quad (2.18)$$

which overall is described in Figure 2.3.



$$y = f\left(\sum_{i=1}^{n} w_i x_i - b\right)$$

Figure 2.3: First Model for Artificial Neuron [10]

An ANN characteristic is defined by the parameters $\theta = (w_1, w_2, \dots, w_n, b, f)$; where bias b can be treated as another set of weight with summation of an input node x_0. It is always been taken the input value $x_0 = +1$ and the setting $w_0 = -b$. A single – layer NN structure which consists of a single layer input and output accordingly is not a layer of neuron but known as a perceptron. Multilayers of neurons are known of multi – layer NN [10]. The structure of ANN is represented by "n-p-m" network where n is the input of the layer with *n +1* node, *p* nodes is the middle or hidden layer and *m* nodes as the output layer. A typical multi – layer perceptron (MLP) is normally a two layered NN which the neurons will perform the same function on the input which usually composites of the weighted sum and differentiable nonlinear activation function or transfer function [10]. The structure is represented by Figure 2.4.

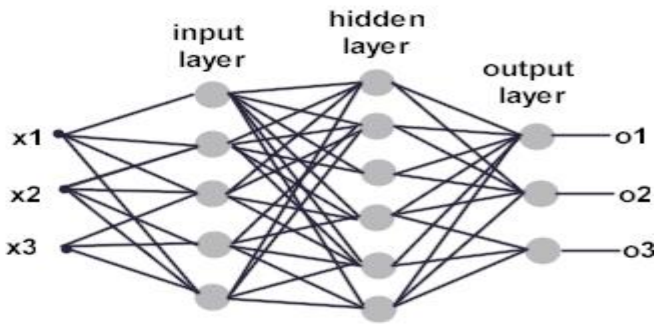


Figure 2.4: MLP Network [10]

2.1.3 NN – PID Controller

ANN is a tough task to control when used as a controller where it requires the same property in the classical or modern control design. Before the Neuro controller (NC) is design it needs to learn and adapt better to the known or provided plant. This is due to the NC is very sensitive and has a quick response to control a plant but it is able to reach a state of good performance and robustness [17].

Here, by having a hybrid controller, the ANN is used to train the plant behavior and produces the best performance according to the test data pattern that has been provided earlier from training the PID plant.

The PID controller output is the response of the PID controller to the error output feedback. The output error feedback is from the difference of set point value and feedback signal. The process is continued by providing the same error signal to the ANN as input. This is where the control signal that has been generated became a Neuro – PID controller [18].

2.1.4 Summary of Controller Reviews

NO.	Title	Author	Year	Findings
1	Neural Network for Control System	Antsaklis, P.J	1990	> Shows short articles from papers found in demand of NN demand in Control System market
2	The Application of Neural Network to Control System : A Survey	Tai, P.; Ryaciotaki-Boussalis, H.A.; Kim Tai	1990	> Summary of survey article that utilizing NN to control linear and nonlinear dynamical system is provided
3	DC Servo Motor Controllers Based on a Neural Network	Lee, C.K.; Chow, T.H.M.; Cheng, D.K.W	1992	> Method of developing a NN based on DT position servo motor controller > Analyse operation of motor affected when operated in closed-loop > Motor driving circuit is nonlinear and characterized by "dead zone" and "saturation" > Steady - state error is not affected by "dead-zone" of motor driving circuit
4	Digital Control of a Servo System Using Neural Network	Shiguo, C.; Holmes, D.G.; Brown, W.A;	1995	> Digital position control presented - implements NN control algorithm to achieve high performance > NN trained in terms of impulse response of a servo application > Result shows superior performance of NN and effectiveness of proposed master - slave architecture to implement
5	A Neuro-PID Speed Controller for DC Drives	Rao, D.H.; Kamat, H.V.;	1996	>A hybrid of PID and Neuro-controller investigation Steady-state response influenced by Neuro - controller once plant dynamics are learned > No PID precise tuning or retuning needed
6	A Survey of Neural Networks Application in Automatic Control	Chowdhury, F.N.; Wahi, P.; Raina, R.; Kaminedi, S.;	2001	> Survey of recent literature in NN applications for automation field > Provides advantages of NN over classical technique proving method to become more applicable in wide areas > NN also applicable for field of detection of faults in dynamics system and controller design purposes
7	Neural Assisted PI/PID Controller Design for a Motor Control System	Chou, P.C; Hsieh S.C.;	2005	> Providing example of simulation for the on motors that shows the enhancement of system > To alleviate the limitations of other controller stated in paper
8	Neural-tuned PID controller for Point-to-point (PTP) positioning system: Model reference approach	Ahmad, W.; Htut, M.M.;	2009	>Proposing and applying a method to replace PID as due to inconsistency > Performance proposed controller better in terms of positioning performance and also robustness to inertia variations
9	Neural Network Based Intelligent Process Control System	Kadam, D.B.; Patil, A.B.; Paradeshi, K.P.;	2010	> Using an ANN architecture brings to more powerful tool for the future - accurately maps nonlinear characteristics between input and outputs quantities

CHAPTER 3

METHODOLOGY

3.0 Research Methodology

Generally research methodology is known to be a guideline system for solving a problem, with specific components such as phases, tasks, methods, techniques and tools. A methodology can be considered to include multiple methods, each as applied to various facets of the whole scope of the methodology.

3.0.1 Research Methodology

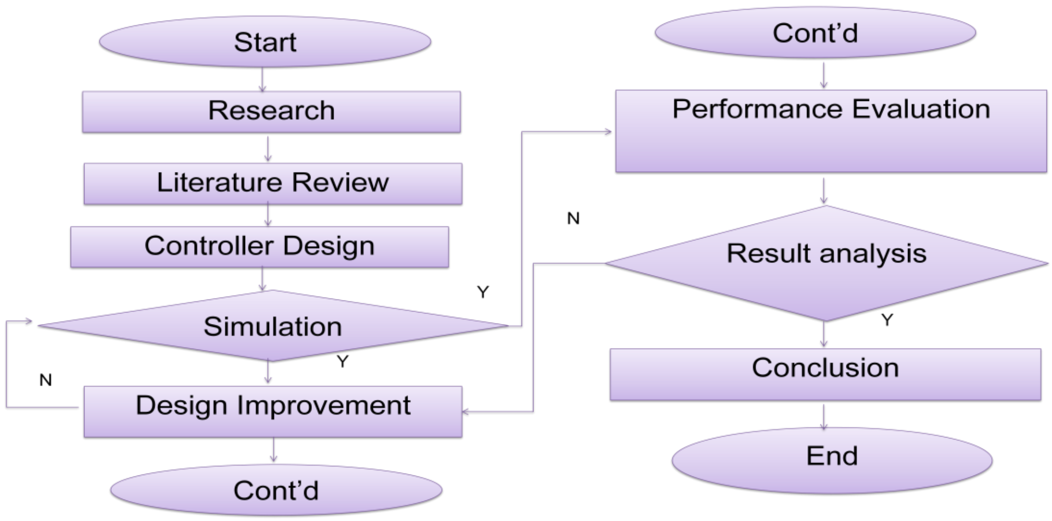


Figure 3.1: General Design Flow

Referring to Figure 3.1, the project is a simulation base research. Specifically, it is a study of development of PID and NN Controller for Servo Motor. First and foremost, the project will begin with the research on several issues regarding DC servomotor, PID and advanced controllers in order to obtain the suitable problem statement on the study case which will be mentioned in the research methodology below.

The project will proceed with the literature review on the DC Servomotor, continued by the chosen controller that will be used in order to control the servo motor which is the PID and NN controller with the collective information. The study covers the ideal application on controller, ideal tuning method on the speed or position of motor and also in obtaining the ideal references according to past research papers that have been concluded in order to obtain the correct algorithm and simulation.

After completing the literature review, the study will proceed by designing the suitable simulation for the DC Servo Motor with its controller. Basically there will be 3 simulation designs of controller that will be tested which are PID controller, NN controller and NNPID controller at the end of the research. Then later, the obtained results of the development will be compared and evaluated in order to obtain the best conclusion result in which controller would provide the best performance in method of tuning.

Lastly, all the studies and discussion that has been obtained throughout the case study will then be compiled in the final report for assessment. Apart from that, recommendations on improvisation and also conclusion of the case study will also be discussed in the report.

3.0.2 Methodology for FYP I - DC Servomotor and PID

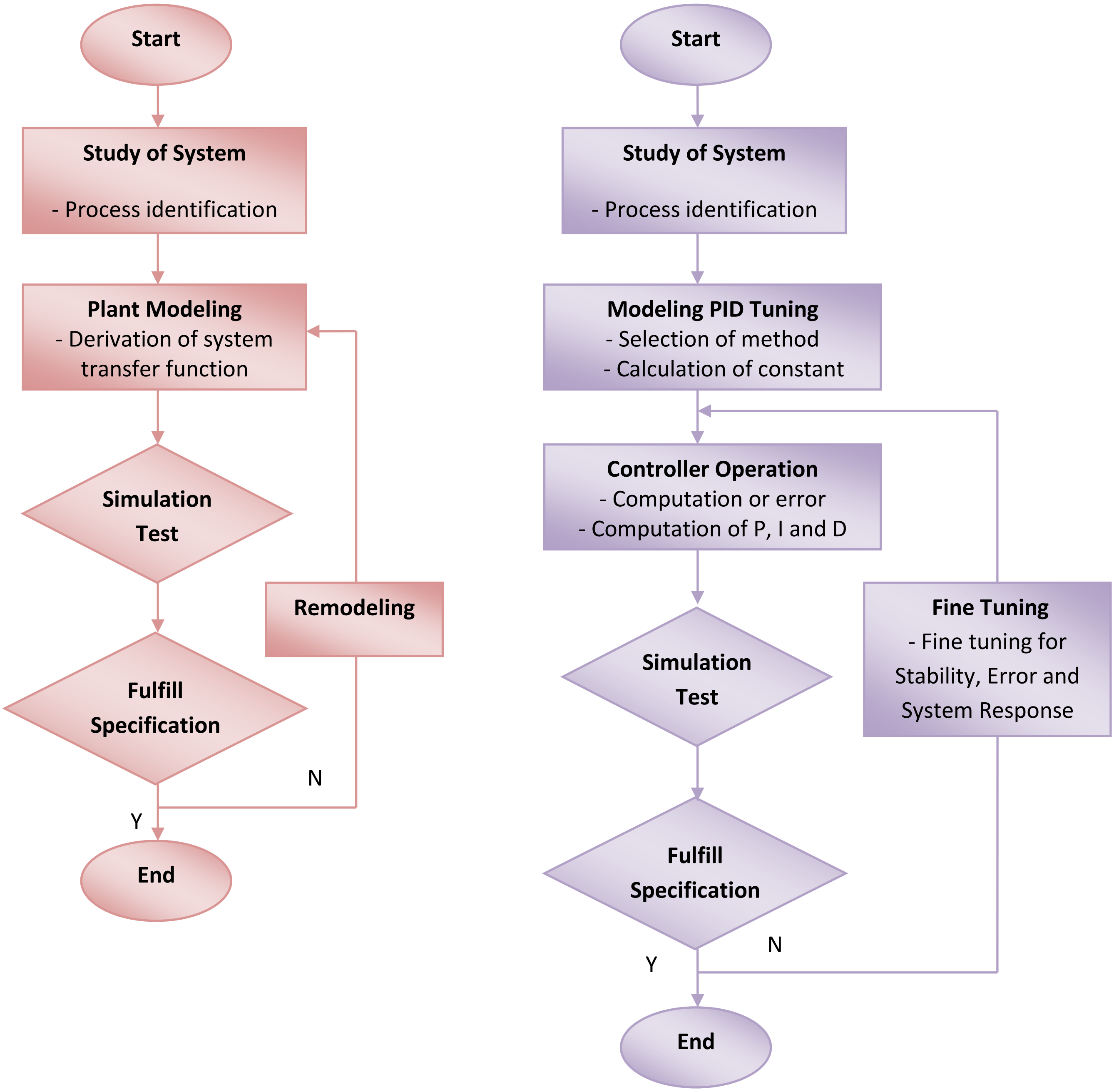


Figure 3.2: Methodology Flowchart DC Servomotor (left) and Methodology Flowchart PID Controller (right)

3.0.3 Methodology for FYP II – NN and NNPID Controller

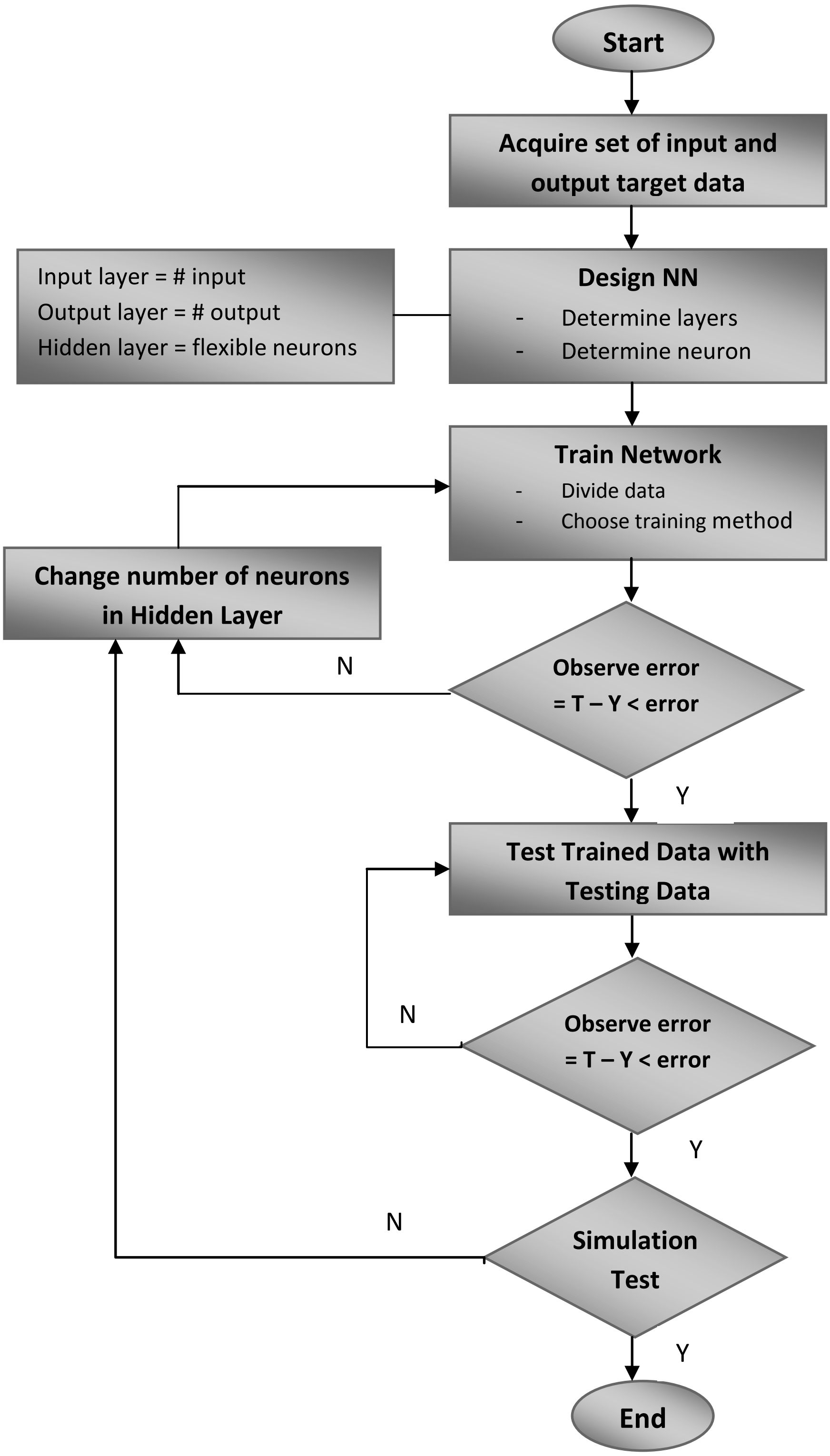


Figure 3.3: Methodology Flowchart NN Controller

3.1 Gantt chart or Key Milestones of Project Activities

For the first semester of final year project, the main activities are doing research and also running the samples of simulation to make sure that the systems that will be develop in Final Year Project II are visible and useful. Gantt chart is the graphical approach to visualize the planning of how to achieve the goals of the projects. It is important to plan the flow of the project to avoid from any unforeseen circumstances and challenges. Below is the chart that have been planned throughout Final Year Project I and continued with Final Year Project II proposed plan.

Table 3.1: Gantt chart FYP I

	FYP 1													
TASK /WEEK	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Title Selection														
Preliminary Research														
Process Identification														
Plant Modeling														
Plant Simulation Test														
PID Modeling														
Simulation Test														
PID Model Tuning														
Submission of Reports														

Table 3.2: Gantt chart FYP II

	FYP 2													
TASK /WEEK	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Acquire NN Training Data														
NN Design														
NN Training and Testing														
Progress Report														
NNPID Design														
NNPID Training and Testing														
ELECTREX, SEDEX, VIVA														

3.2 Requirements

For this project the requirement only consists of:

1. Software requirement
    1. MATLAB/SIMULINK – used as a Software Design which is programming the computer to carry out its control calculation and to produce results in simulation

CHAPTER 4

RESULTS AND DISCUSSIONS

4.0 PLANT MODELLING

As discussed in Chapter 2 on the servomotor transfer function,

$$H_1(S) = \frac{\theta_o(s)}{\theta_i(s)} = \frac{2027520}{0.258s^3+96s+11050\,s} \qquad (4.1)$$

A model block is created to represent the transfer function using MATLAB/SIMULINK software as per Figure 4.1. The model represents the plant of the system which will then be expended into further simulation. In order to expand the simulation further, the model will then be used as a subsystem of the new block model.

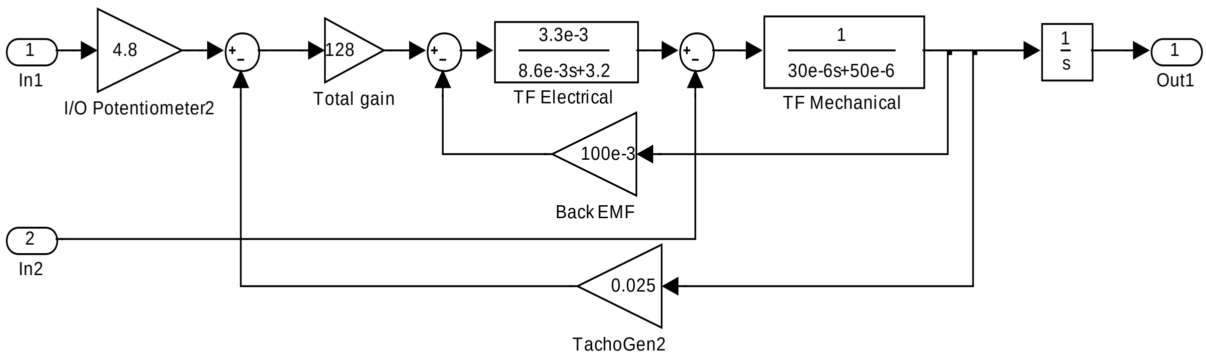


Figure 4.1: Block Diagram of DC Servomotor System of MS150

The plant shown above in Figure 4.1 is a full model of MS150 Servomotor Modular plant without any application of controller. Before any of the controllers is applied, the plant is tested in two different sets of condition which are no load test and with load test. These tests are made to see and evaluate the performances of the servo motor. Load of the motor is in terms of disturbance.

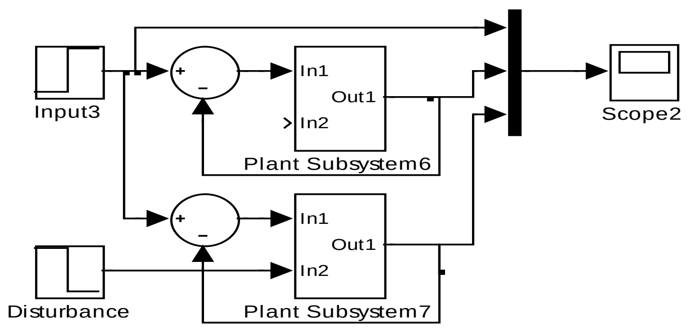


Figure 4.2: Modeling MS150 with No Controller

The plant shown in Figure 4.2 is without any application of controller. As stated before, the plant is tested in two different sets of condition which are no load test and with load test. These tests are made to see and evaluate the performances of the motor. Figure 4.3 shows the performance of the plant modeling.

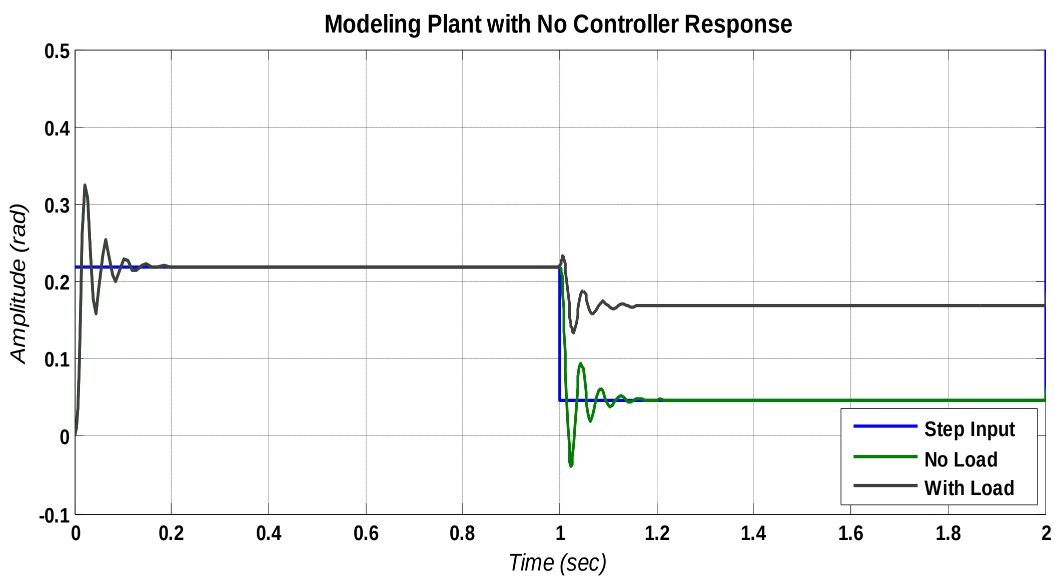


Figure 4.3: Modeling Plant MS150 with No Load and with Load Response

4.1 PID CONTROLLER

For a PID controller, in order to tune the plant to obtain tuning values to obtain better performance, it is essential to obtain its ultimate values. Here, Ziegler – Nichols (Z – N) Closed Loop Tuning method is applied. Hence, to obtain its ultimate values, adjustment in the K_p gain value is made to obtain the suitable the oscillation that has the same frequency and amplitude.

4.1.1 Gaining ultimate values for PID controller using ZN Method

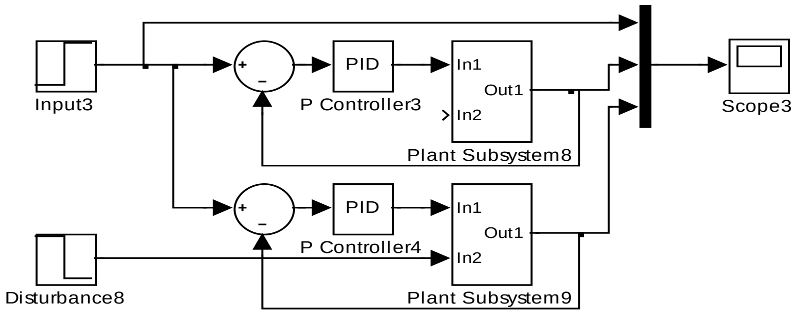


Figure 4.4: Modeling PID with No Load and With Load

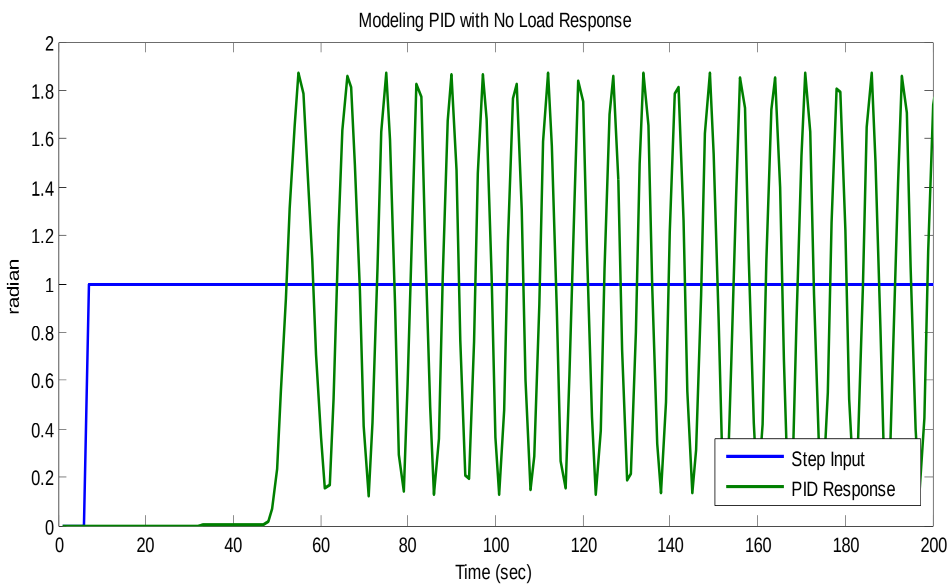


Figure 4.5: Modeling PID with No Load Response

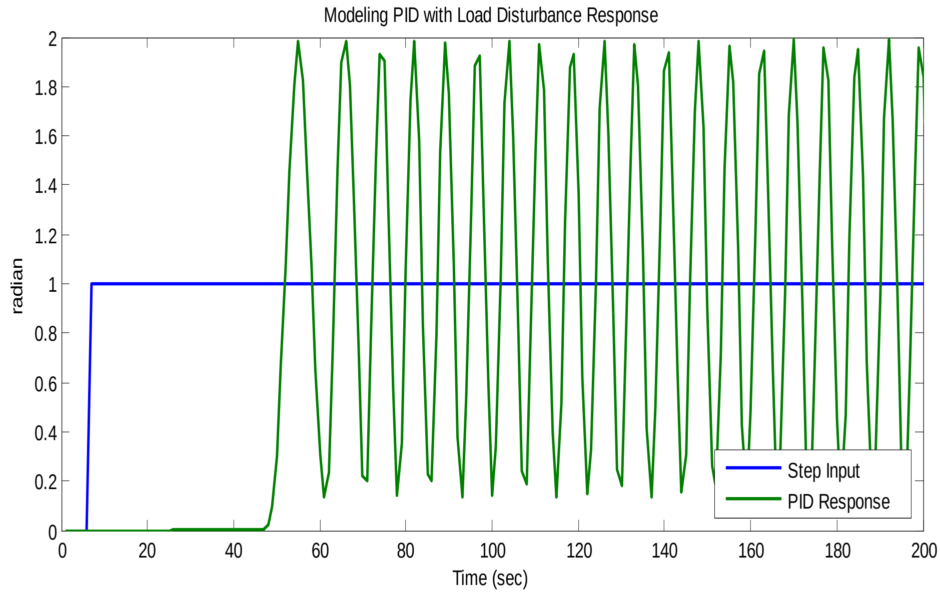


Figure 4.6: Modeling PID with Load Response

With the K_p value set to be 2.0373, the obtained response of the ultimate period, P_u 0.03 sec while the ultimate gain, K_u, is 1.63. From the obtained value, the PID parameters are calculated as follow.

Table 4.1: PID Parameters

Control Type	Kp	Ki	Kd
P	0.815	-	-
PI	0.73	29.2	-
PID	0.978	65.2	0.00367
PD	0.978	-	0.00367

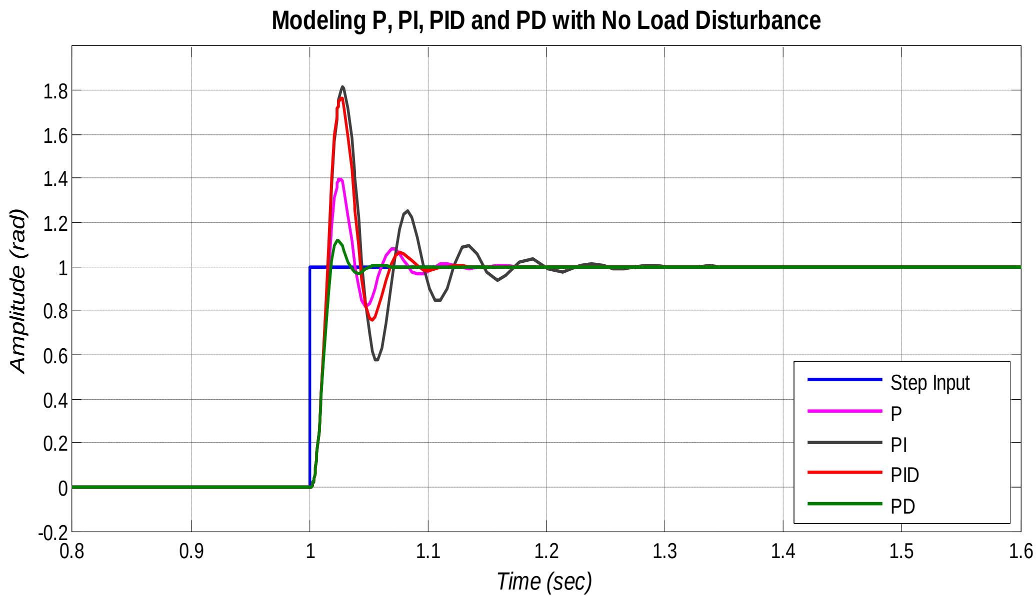


Figure 4.7: PID Control Performances with No Load Disturbance

From the Figure 4.7, it is obtained that the evaluation of control performances in terms of overshoot, time response and SSE are given in Table 4.2 below.

Table 4.2: PID Control Performance with No Load Disturbance

	P	**PI**	**PID**	**PD**
O.S(rad)	0.38	0.8	0.88	0.12
t_r (msec)	16.7	16.7	13.3	14.6
t_s (msec)	109.7	275	111.7	62.8
SSE(rad)	-	-	-	-

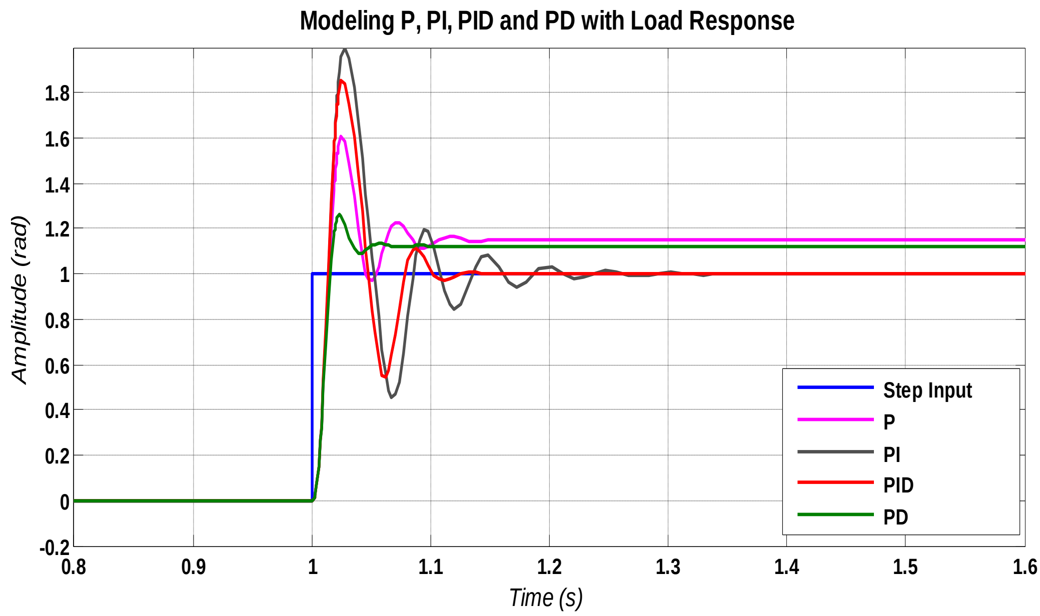


Figure 4.8: PID Control Performances with Load Response

From the Figure 4.8, it is obtained that the evaluation of control performances in terms of overshoot, time response and SSE are given in Table 4.3.

Table 4.3: PID Control Performance with Load Disturbance

	P	**PI**	**PID**	**PD**
O.S (rad)	0.6	0.96	0.8	0.26
t_r (msec)	13.3	13.2	11	15
t_s (msec)	159	348	129	66
SSE (rad)	0.15	-	-	0.12

From Table 4.3, the best controller with the best parameter value is investigated whereby it shows that the P and the PD controller produces Steady – state Error. This is due to both of the controller does not have integral mode in order to improve its steady – state response. Thus, leading to the consideration between PI and PID controller where after considering the performances where PID provides the best performances in terms of all the criteria listed in the table. Therefore, PID parameters are chosen as a controller for the use in controlling the servomotor.

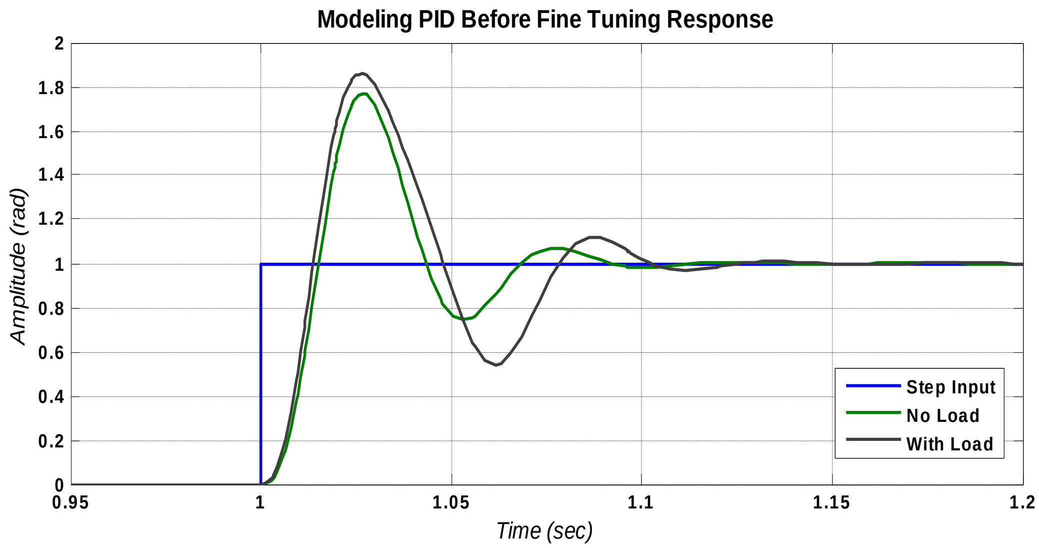


Figure 4.9: Modeling PID before Fine Tuning Response

In order to obtain a better response in reducing the oscillation and reducing the overshoot response of the PID controller, the controller parameter is later being fined tune to produce a better response. However, the result obtained are not as expected where even though the overshoot has successfully been decreased and the is still no Steady – State error, the rise time and settling time increased by 0.5 second. After further consideration, the fine tuned PID is still chosen as a better controller for further investigation with value of K_p remained, K_i decreased by 3 times and K_d increased by 3 times.

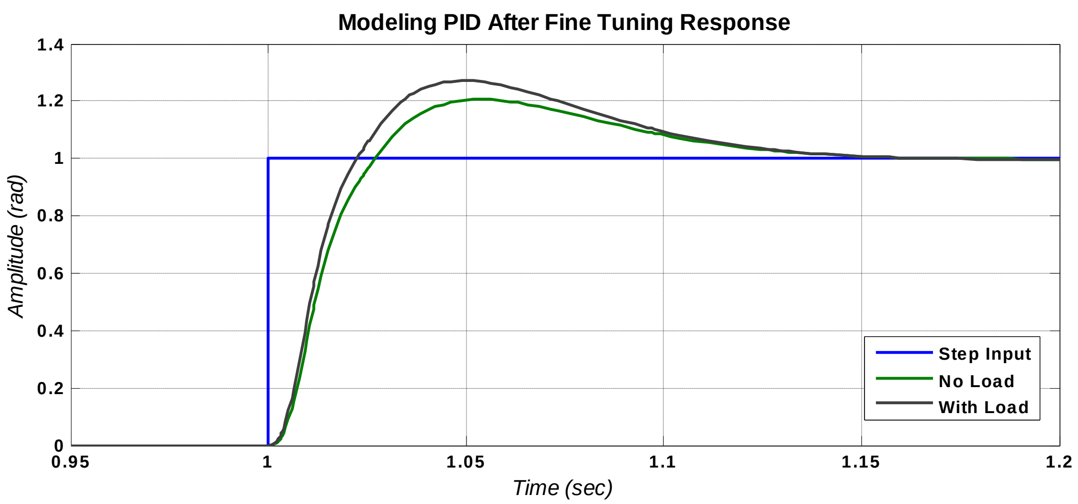


Figure 4.10: Modeling PID after Fine Tuning Response

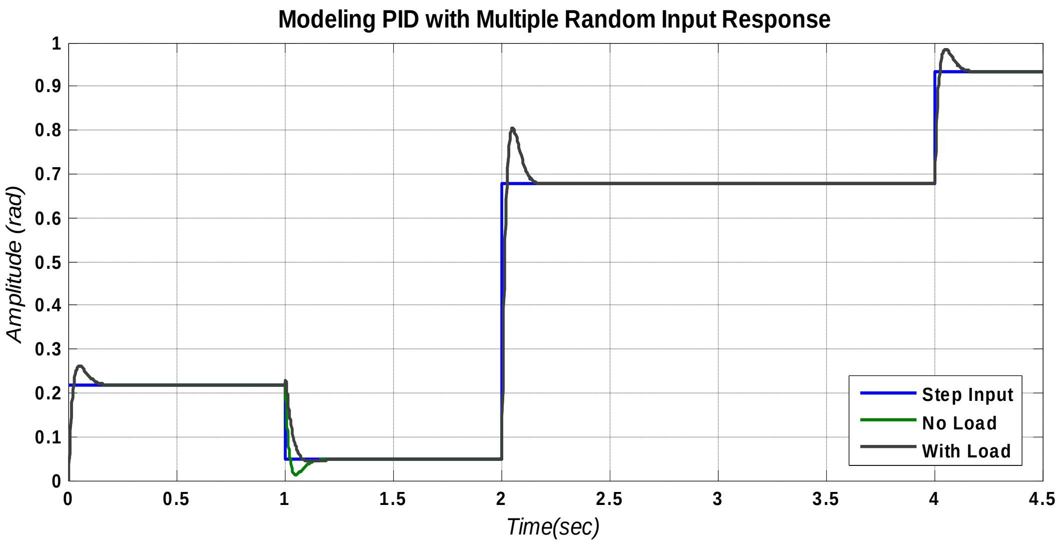


Figure 4.11: Modeling PID with Multiple Random Input Responses

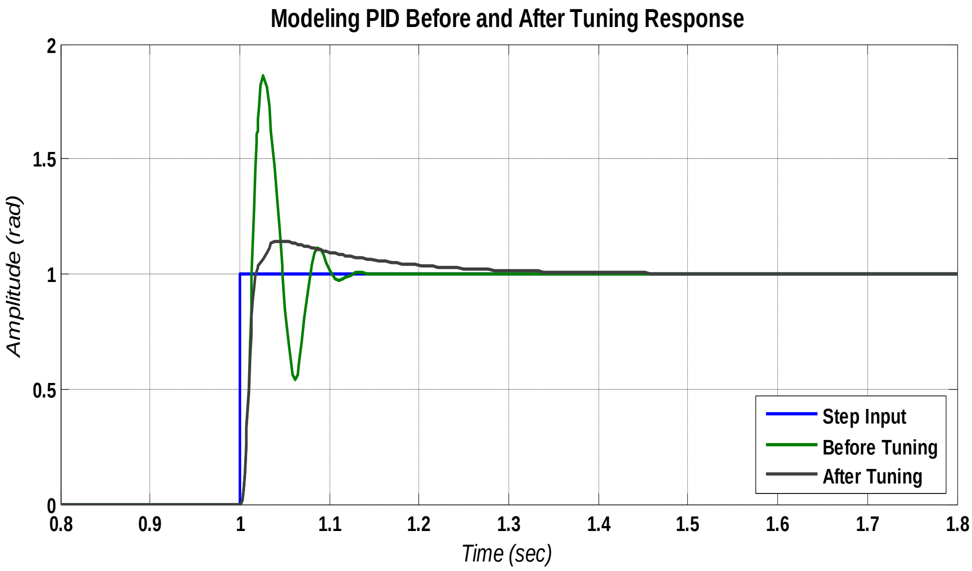


Figure 4.12: Modeling PID before vs. after Fine Tuning Responses

4.2 NN – PID Controller

ANN can be use as a controller which will require detailed and careful design for most plant. However a neural network is not able to work alone in this scenario. This is due to a standalone neural network is a tough task to design. In this scenario, the ANN controller is used to assist the PID controller as a hybrid which combines the learning capabilities of an ANN based on the controller. The simulation is run by using *nntraintool* and an M-File coding which then will be generated into a NNet Simulink block.

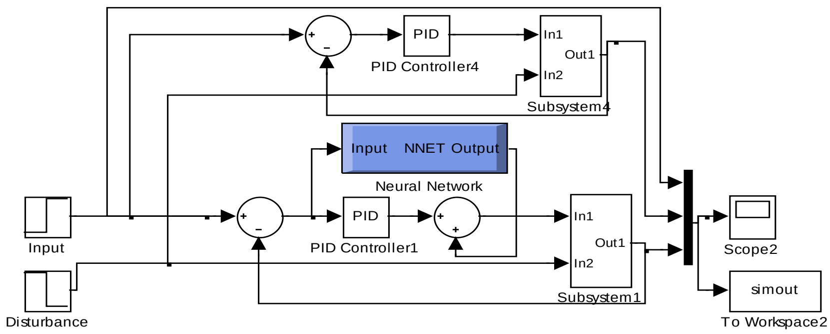


Figure 4.13:Block Diagrams, PID Controller (top) and neural assisted PID (lower)

In order to test the NNet with the PID, a few steps are taken into consideration where:

1. A set of input and target data set from simulation
2. Design of NN to determine layers, and neuron in each layers (input layer, output layer and hidden layer)
3. Training of the network – input and output data set are divided into equal number of data's for training and testing, choosing the training method, changing the required number of neurons in hidden layer to provide the least error and observation of the error where error = target – output

After the steps has been taken into consideration, then only the training data will be tested with the available testing data (not included in training). This is to observe the output and the error where once again the error = target – output. After the suitable number of neurons obtained then the trained and tested NN will be generated into a Simulink Block to perform the simulation test. The M-File of the NN network is available in Appendix 1. Figure 4.13 below shows the *nntraintool* that is used to train the NNet.

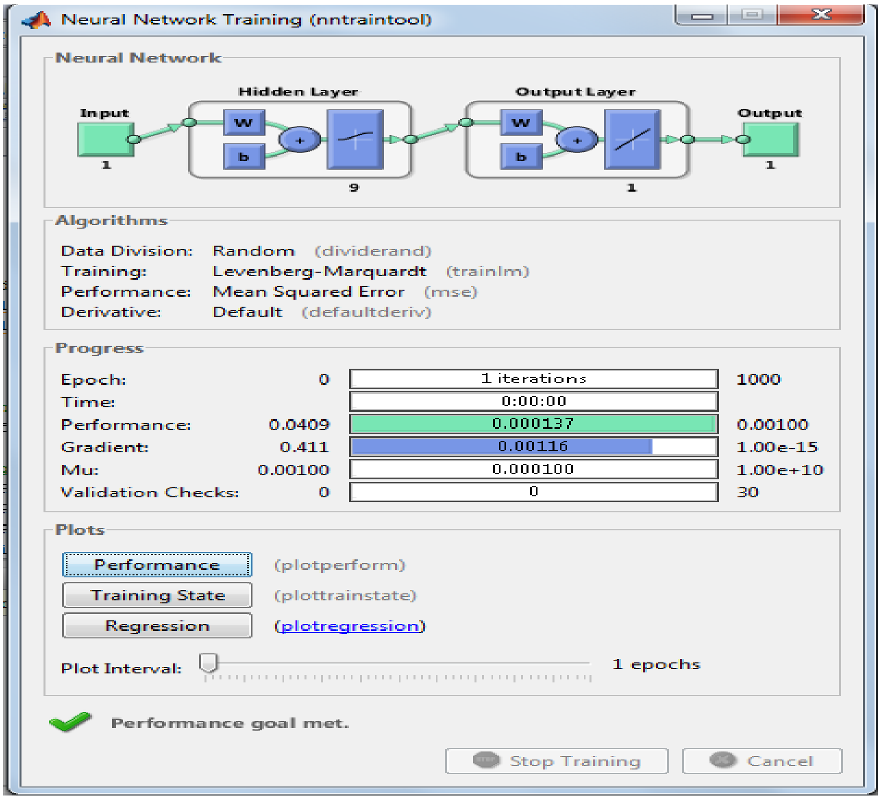


Figure 4.14: *NNtraintool* provides information on training method, training performance, regression and type of activation function used

The *nntraintool* decides to use random values in this phase for all weights and biases instead of zeros. Which provides an end result of *nntraintool* generates a set of random values and assigns them to the weight and biases before each training is conducted. However, as the process goes by, during the training, the values will then changed according to the learning method that has been chosen. Lastly, the weight and bias values will be fixed and stored in ANN.

In order to obtained this end result, the training must be conducted multiple sets of times and the most optimized ANN is obtained through observing the training error and testing error differences. In order to know the best performance of ANN, Pearson's R performance indicator in the form of correlation coefficient between the targets and outputs in the end of training is observe. For R almost or equal to 1 it is said that the training is considered successful meanwhile for R almost or equal to 0 the training is considered as not successful.

After the suitable number of neurons obtained then the trained and tested NN will be generated into a Simulink Block to perform the simulation test. Here, the NN is trained up until 10 neurons of hidden layers in order to observe and to obtain the best optimized learning error. Then, by generating the trained net NN into a Simulink block, the end result of a hybrid PID – NN is obtained.

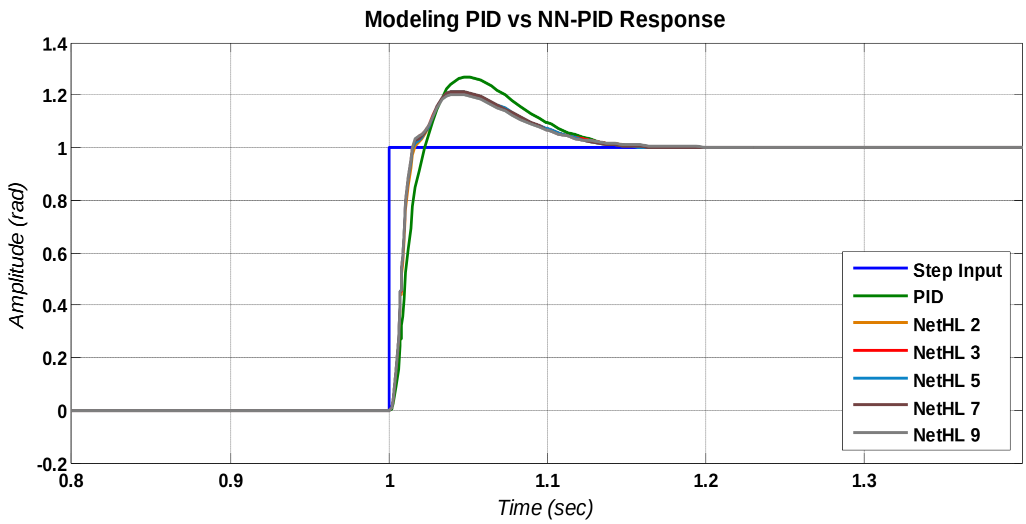
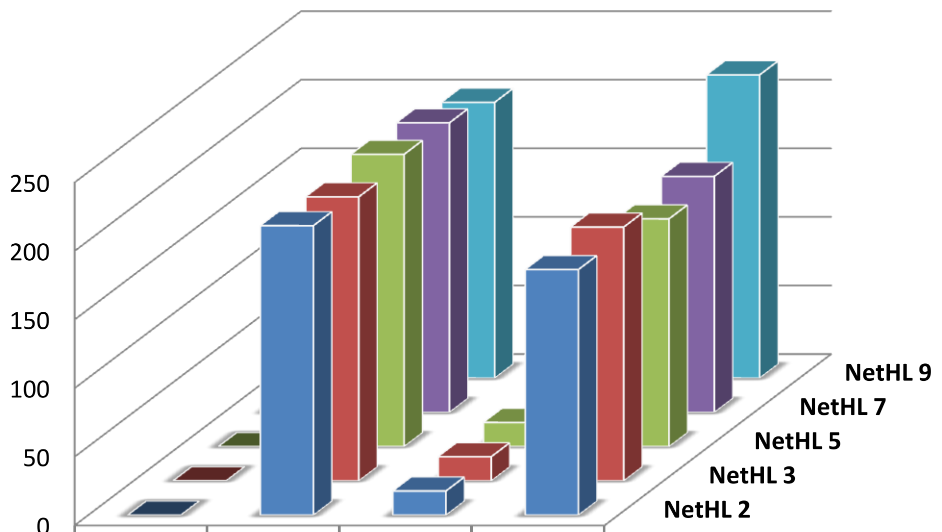


Figure 4.15: PID vs PIDNN response with multiple Hidden Layer Neurons sets to consider the best performance

Table 4.4: Chart and Table Comparison of Performances of PIDNN with different sets of Hidden Layer Neurons



	SSE (rad)	O.S (mrad)	tr (msec)	ts (msec)
NetHL 2	0	211	17,6	179
NetHL 3	0	207	17,6	185
NetHL 5	0	213	17,6	166
NetHL 7	0	211	17,6	172
NetHL 9	0	201	17,6	221

From Table 4.4, it is obtained that PID – NN with a hidden layer containing 9 neurons has the most suitable performances compared to others. It is seen that the NN controller has managed to assist the PID controller in improving the controller performances in terms of less overshoot, faster rise time, fast settling time and with no SSE. The NetHL9 satisfies the wanted criteria.

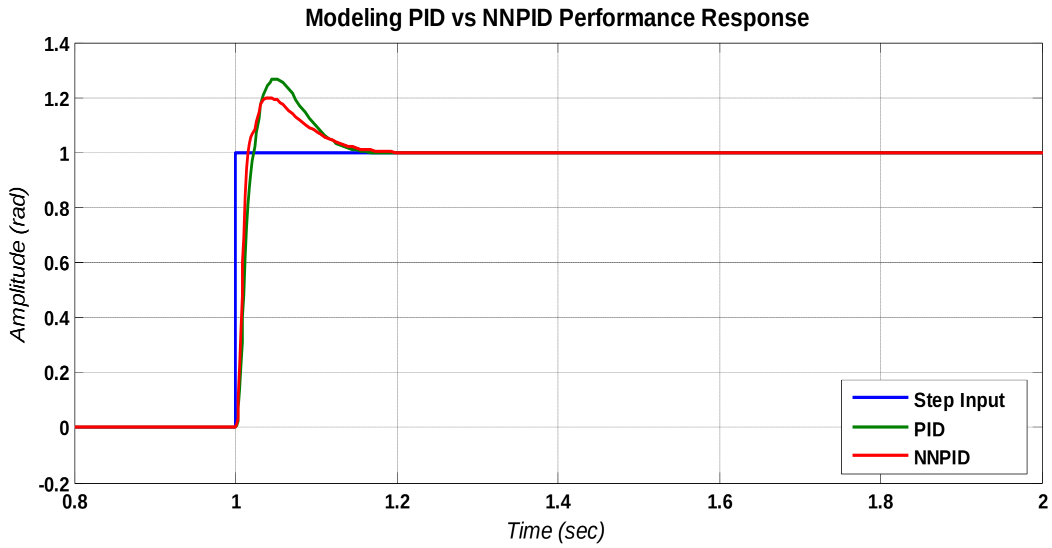
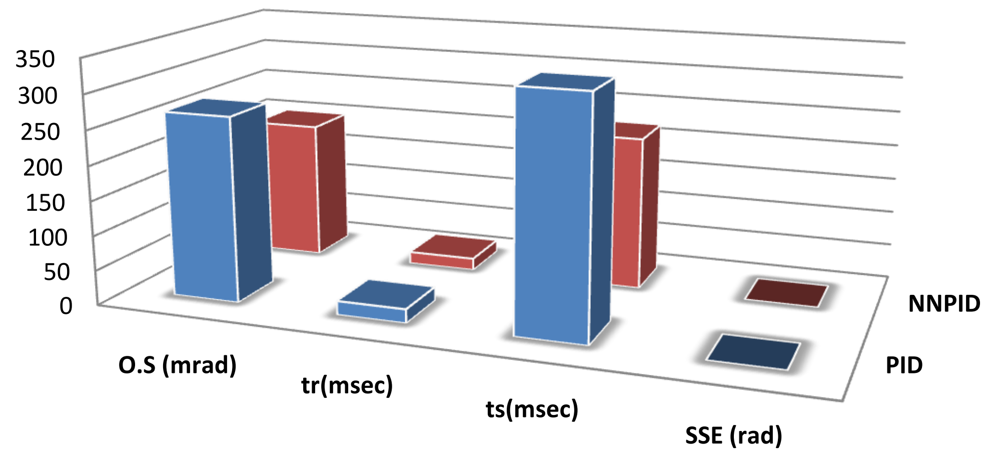


Figure 4.16: Modeling PID vs. PIDNN response with the best 9 Neuron Hidden Layer Performance

Table 4.5: Comparison of Performances between PID and PIDNN with NetHL9



	O.S (mrad)	tr(msec)	ts(msec)	SSE (rad)
PID	267	20	336	0
NNPID	201	17,6	221	0

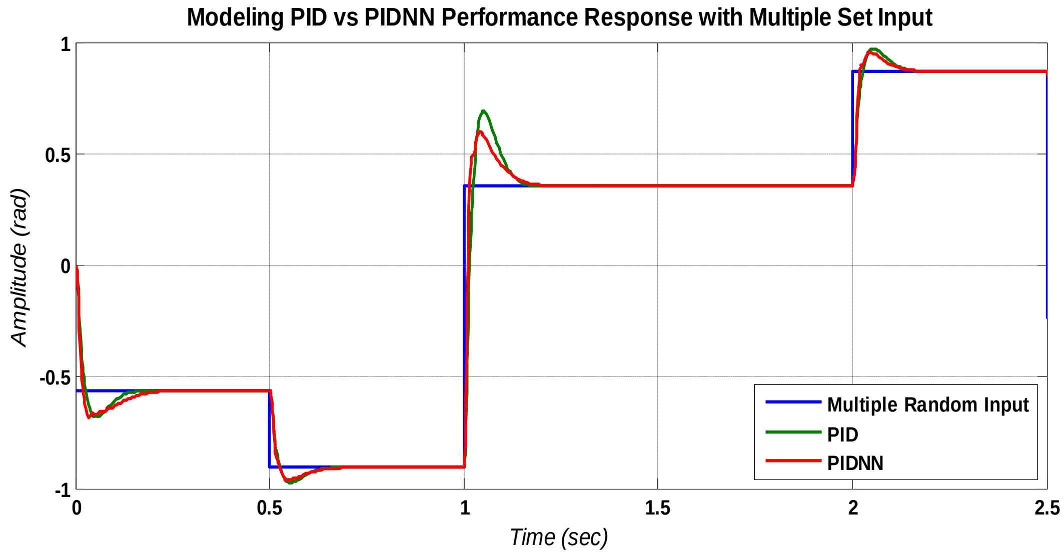


Figure 4.17: Modeling PID vs. PIDNN Performance Response with Multiple Set Input

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

Servomotors are widely applied in varieties of industrial application which requires reliable and precise measurement for the parameters control (position and speed) on the mechanism joints. The aim of the project is to design and develop advance controllers for the servomotor application and also to observe, evaluate and compare the control performances of the controllers provided.

In order to understand and analyze the performances of the conventional controller and the advanced controller, it is a need to be able to design and develop the correct control strategy that is relevant to this project. The PID controller is able to perform good performances but also causes inconsistence performance based on the information from the literature review obtained from Chapter 2 and also results obtained from the analysis of modelling. Therefore, to improve the system consistencies, a new controller which is the Artificial Neural Network (ANN) controller is introduces to assist the PID controller in order to obtain better performances in controlling. However, due to the randomness of the training NN data, it is hard to predict the exact time of simulation where the wanted least error can be obtained and reliable.

From the results obtained from NNPID, the hybrid controller manages to obtain better performances than PID. This proves the theory in the literature review that the NN will manage to assist the PID in order to obtain better performances than the PID controller itself. As a conclusion, the objective of providing better results by implementing an advanced controller is achieved for the implementation on the servomotor MS150 Modular.

For further recommendation, the study of the NN and NNPID can be tested on more large number of neurons in order to see better the controller's contribution to the servomotor performances. It is also recommended that the hybrid controller NNPID dataset be trained to be used as a single standalone NN controller for the servomotor simulation performances.

REFERENCE

[1] Servo Motor System, *Yeditepe University Engineering Faculty, Mechanical Engineering Laboratory*.(n.d.)., http://me.yeditepe.edu.tr/courses/me402/lab%20manuals/Servo_Motor_System.pdf (January 31st 2012)

[2] M. Akar; I. Temiz;, "Motion Controller Design for Speed Control of DC Servo Motor," International Journal of Applied Mathematics and Informatics, Vol. 1, No. 4, pp. 131-137, 2007.

[3] Laubwald, E. Control Systems Principle.co.uk. (n.d.). Servo Control System 1 : DC Servomechanism. Retrieved January 31st 2012

[4] Machinetoolhelp.com. Advantages and Disadvantages of Stepper Motors & DC Servo Motors. (2003 – 2010). Retrieved 28th December 2011 from http://www.machinetoolhelp.com/Automation/systemdesign/stepper_dcservo.html

[5] S. Chopra, R. Mitra and V. Kumar, 2005, "Fuzzy Controller: Choosing an Appropriate and Smallest Rule Set," International Journal of Computational Cognition, Vol. 3, No. 4.

[6] M-Y. Shieh, T-H.S. Li, 1997, "Design and Implementation of Integrated Fuzzy Logic Controller for a Servomotor System," Mechatronics 8 (1998), 217-240

[7] Md Kamal, M; Mamat, N. "Controller Design for Servo Motor" I*ndustrial Electronics & Applications, 2009. ISIEA 2009. IEEE Symposium* on , vol. 2, no., pp. 926-929, October 4-6, 2009.

[8] Mohamad Saleh, S. (n.d.). "Implementation of MRAC, SVMPC and PID Control Based on Direct Digital Control Application for DC Servomotor". Retrieved February 6th, 2012

[9] Ahmad, W.; Htut, M.M.; , "Neural-tuned PID Controller for Point-to-point (PTP) Positioning System: Model Reference Approach," *Signal Processing & Its Applications, 2009. CSPA 2009. 5th International Colloquium on* , vol., no., pp.140-144, 6-8 March 2009

[10] Nguyen, H.T, Prasad, N.R, Walker, C.L & Walker, E.A. (2003). *A First Course in Fuzzy and Neural Control*. New York: Chapman & Hall/ CRC

[11] Hagan, M.T.; Demuth, H.B.;, "Neural Networks For Control," *American Control Conference, 1999. Proceedings of the 1999* , vol.3, no., pp.1642-1656 vol.3, 1999

[12] Shiguo, C.; Holmes, D.G.; Brown, W.A.; , "Digital Control Of A Servo System Using Neural Networks," *Industry Applications Conference, 1995. Thirtieth IAS Annual Meeting, IAS '95., Conference Record of the 1995 IEEE* , vol.1, no., pp.129-133 vol.1, 8-12 Oct 1995

[13] Antsaklis, P.J.; , "Neural Networks For Control Systems," *Neural Networks, IEEE Transactions on* , vol.1, no.2, pp.242-244, Jun 1990

[14] Chowdhury, F.N.; Wahi, P.; Raina, R.; Kaminedi, S.;, "A Survey Of Neural Networks Applications In Automatic Control," *System Theory, 2001. Proceedings of the 33rd Southeastern Symposium on* , vol., no., pp.349-353, Mar 2001

[15] Tai, P.; Ryaciotaki-Boussalis, H.A.; Kim Tai; , "The Application Of Neural Networks To Control Systems: A Survey," *Signals, Systems and Computers, 1990 Conference Record Twenty-Fourth Asilomar Conference on* , vol.1, no., pp.148, 5-7 Nov 1990

[16] Lee, C.K.; Chow, T.H.M.; Cheng, D.K.W.; , "DC servo motor controllers based on a neural network," *Intelligent Systems Engineering, 1992., First International Conference on (Conf. Publ. No. 360)* , vol., no., pp.287-292, 19-21 Aug 1992

[17] Chou, P.C; Hsieh S.C.;, " Neural Assisted PI/PID Controller Design for a Motor Control System," *Computational Intelligence for Measurement Systems and Applications, 2005. CIMSA. 2005 IEEE International Conference on*, vol., no., pp.152-155 , 20-22 July 2005

[18] Rao, D.H.; Kamat, H.V.; "A neuro-PID speed controller for DC drives,". *Power Electronics, Drives and Energy Systems for Industrial Growth, 1996., Proceedings of the 1996 International Conference on,* vol. 2, no., pp.757-763, 1996

[19] Shinners SM, 1978, Modern Control System Theory and Application. Addison Wesley

[20] Phillips CL, Nagle HT, 1990, Digital Control System Analysis and Design, 2nd Ed. Prentice-Hall.

[21] Z. Runjing, Y. Weiting, 1st Initial. Zhangfei, "Application of NN-PI Controller in Direct Current Motor Servo System ," *The Eighth International Conference on Electronic Measurement and Instruments, ICEMI\'2007*, Vol. 4, no. , pp. 468 - 471, 2007.

APPENDIXES

APPENDIX A

M-FILE FOR NN Controller

```
% Training data
P = [];  T = [];
for idx = 1:1263
   if mod(idx, 2) == 1
      P = [P e(idx, 1)];
      T = [T f(idx, 1)];
   end
end

% Testing data
P1 = [];  T1 = [];
for idx = 1:1263
   if mod(idx, 2) == 0
      P1 = [P1 e(idx, 1)];
      T1 = [T1 f(idx, 1)];
   end
end

% Designing network
net = newff(P, T, 9, {'logsig'});

% Training network
net.trainParam.goal = 1e-3;
net.trainParam.max_fail=30;
net.trainParam.min_grad = 1e-15;
net = train (net, P, T);

% Validation of network
Y = sim(net, P);
E = T - Y;
msError = mse(E);
disp(msError);
figure: plot ((1:632)', T, (1:632)',Y);

% Testing network
Y1 = sim(net, P1);
E1 = T1 - Y1;
msError1 = mse(E1);
disp(msError1);
figure: plot ((1:631)', T1, (1:631)',Y1);
```