MODEL REFERENCE ADAPTIVE CONTROL FOR MAGNETIC LEVITATION SYSTEM

Thesis submitted in partial fulfillment of the Requirements for the award of the degree of

BACHELOR OF ENGINEERING

IN

ELECTRICAL & ELECTRONICS ENGINEERING

BY

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Certificate

This is to certify that the contents of the thesis entitled **“MODEL REFERNECE ADAPTIVE CONTROL FOR MAGNETIC LEVITATION SYSTEM”** is a bonafide work carried out by Mr. Sree Aslesh Penisetty, Ms. Dhriti Kumari under my supervision and guidance in partial fulfillment of the requirements for the degree of Bachelor of Engineering in Electrical and Electronics Engineering.

The contents of the thesis have not been submitted earlier for the award of any other degree or certificates and we hereby commend the work done by him in this connection.

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Certificate of Approval

This project titled **“MODEL REFERNECE ADAPTIVE CONTROL FOR MAGNETIC LEVITATION SYSTEM”** carried out by Mr. Sree Aslesh Penisetty and Ms. Dhriti Kumari**,** is hereby approved as the creditable study of Engineering in Electrical and Electronics Engineering and is presented in a satisfactory manner.

It warrant its acceptance as a prerequisite in partial fulfillment of the requirements for the award of the **BACHELOR OF ENGINEERING** degree in Electrical and Electronics Engineering at Birla Institute of Technology, Mesra ,Ranchi, India.

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ABSTRACT

Control of complex machines such as cars, robots, fighter jets has always been a lasting challenge in the academic field of control theory. The control of machines is always ever relative as it can always be made to respond better. The proposed project is to achieve precise control by using and algorithm known as Model Reference Adaptive Control.

This method of control has both direct and indirect modes of approach while we will be using indirect method for simplicity of simulation and computation. The control with this algorithm is extremely precise and to prove it we have simulated it using the model of a magnetic levitation system which is a complex second order non-linear differential system.

The most significant contribution of this thesis is the simulation and review of Model Reference Adaptive Control for a very sensitive second order non-linear system proving the point to be reviewed that Model Reference Adaptive Control can be used in complex applications for precise control and to obtain the best control response possible for a given input reference. This project is to be further developed with a hybrid of PID and Model Reference Adaptive control to increase the robustness of the control algorithm while reducing the settling time of the response.

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CHAPTER I

INTRODUCTION

1.1 NATURE OF THE PROBLEM:

The main focus of the thesis is towards control of a magnetic levitation system and its position control using Model Reference Adaptive Control. The control problem is usually associated with multiple response problems as time setting delay, instability or harmonics and sub-harmonics of nonlinear systems with nonlinear responses leading to resonance peaks causing instability of the system. For a change in reference input the adaptability or response of the control law depends not only on the algorithm but also based on the adaptability and flexibility of the parameters. This has been proven by various parameter tuning algorithms such as DeepReplay, auto_ml, GpyOpt, H20 etc. The only lacking parameter in these modes of algorithm parameter tuning is the ability to take in the model based output response in collaboration with the real time output. This problem is answered with the help of Model Reference Adaptive Control.

1.2 PARAMETER TUNING FOR A MRAC CONTROLLER:

Conventional methods of control algorithms are becoming unreliable due to the parameters and external fluctuations at the time of application of the system in a real time environment. However fine-tuned a controller may be there still arise cases in which the controller moves towards instability of the system with or without knowledge of the newly placed poles with reference to the input given.

With experience in control and knowledge of the currently used algorithms it is conclusive to say the we need a controller which not only gives a control input based on the input but also is adaptable to varying noises and unknown parameters which may affect the system in real-time operation and cope with them in the most effective and computationally efficient method.

This is done by not only considering the real –time output of the system and using it as feedback but also by consider the output based on the given input form a similar model of the system. The parameter tuning is done based on these parameters generated by the algorithm.

This thesis presents a real time control of a sensitive second order non-linear system i.e a magnetic levitation system controlled by and Indirect Model reference Adaptive Control.

1.3 SIMULATION OF INDIRECT MRAC CONTROLLER AND ANALYSIS:

There is need of an accurate method for control of complex nonlinear systems. This thesis presents a highly efficient and reliable method based on Model Reference Adaptive Control with automated parameter tuning. The main contribution of the indirect mode of the Model Reference Adaptive Controller is in reducing the settling time pertaining to the response of the controller. This needs to be tested experimentally or simulated for this to be proved. As we are still awaiting the materials, this was simulated in Matlab using Simulink and the results were tested with different parameters of adaptation for the best possible adaptive reference control algorithm.

This simulation provides an insight into the variation of parameters with respect to the change in input and also the response. The graphical insight better portrays the variation in the parameters to gain knowledge and visualize the graphs in an enhanced manner.

1.3 ORGANIZATION OF THE THESIS:

The organization of the 7 chapters is as follows.

Chapter II gives a literature review regarding wavelet transform, fuzzy logic and ANFIS.

Chapter III contains application of wavelet transform for fault analysis for overhead transmission lines.

Chapter IV introduces the basic concepts pertaining to Adaptive neuro fuzzy inference system (ANFIS).

Chapter V describes the application of Monte Carlo simulation for fault location and error analysis.

Chapter VI contains the results and discussions for different case studies.

*Chapter VI I*deals with the conclusion and scope for future work.

CHAPTER II

LITERATURE REVIEW

Adaptive Control is the control method used by a controller which must adapt to a controlled system with parameters which vary and are initially uncertain, while in a Model Reference System, the output of the system is compared to the desired response from a reference model. So, the general idea behind Model Reference Adaptive Control (MRAC) is to create a closed loop controller with parameters that can be updated to change the response of the system and then comparing the output with the reference model. A non-linear magnetic levitation system is used in this project to show different methods of MRAC. We describe the history of MRAC beginning with the adaptive system, comparing the 3 different methods control algorithm and continue with the evolution of Model Reference Adaptive Control (MRAC) and overview of some interesting applications in modern machines in the next chapter.

2.1 MRAC Overview

Magnetic levitation system is very popular experimental hardware in control laboratory for position control of the steel ball. The presence of high nonlinearity and parameter uncertainty makes it difficult to control the ball position through a conventional feedback controller. To overcome this problem, an adaptive proportional integral and derivative (PID) controller, based on model reference adaptive control (MRAC) is proposed, i.e. firstly, a feedback linearization technique (exact linearization with state feedback) is applied to obtain a linear system and secondly, the linearization is made via direct cancellation of nonlinear functions, which represent the phenomenological model of the system. To deal with the presence of uncertainty in the system model, an adaptive controller is used. The controller is based on model reference adaptive control to estimate the functions that contain the nonlinearities of the system. The exact linearization and the adaptive controller were implemented in a simulated environment (Matlab-Simulink). The linear adaptive controller structure guarantees the parameters adaptation and the overall stability of the system. The proposed controller utilizes the MIT rule for adaptation mechanism. The results show that the controller output signal tracks a reference input signal with a small error. To track the position of a ball, many controllers are used, such as fuzzy logic control, sliding mode control etc. For simplicity, proportional-integral-derivative (PID) controllers are also used. But the time-varying, environmental conditions and inherent nonlinear properties in the system frequently degrade the fixed gain PID controllers' performance. So, to overcome this problem, the gain of the PID controller is adaptive in nature. The adaptive control algorithm is classified into three methods, direct, indirect and hybrid methods. In this project, MIT rule has been used to apply the MRAC approach, which is an important adaption technique that will be discussed later in the chapter.

2.2 HISTORICAL PERSPECTIVE

Motivated by the need for high-performance flight control systems (e.g., X-15 experimental aircraft), there was a significant growth of interest in adaptive controls in the 1950s. Motivated by the need to improve the performance of the fixed-gain control systems, much effort has been spent to address these shortcomings. Some practical examples of the implementation of adaptive control systems are as follows. The authors, P. Jain and M. J. Nigam implemented MIT rule (a popular adaptive control algorithm founded by a group of researchers from the Massachusetts Institute of Technology)for controlling ball and beam system; while the authors, D. Rotondo, F. Nejjari, and V. Puig designed an adaptive control for a quadcopter UAV. In 1951, researchers successfully developed a self-optimizing controller for the combustion engine, and a flight test was successfully conducted. Between 1957-1961, the applications of dynamic programming in adaptive controls were investigated. In 1958, Model Reference Adaptive Control

(MRAC) was implemented to solve flight control problems. Furthermore, in 1965, the Lyapunov theory was introduced to address the stability issue in MRAC and in the 1970s-1980s there were significant developments in the area of self-tuning regulators. Furthermore, gain scheduling was introduced to address the solution of flight control systems. From 1980 onwards, there havebeen significant developments in process control systems, and as a result, adaptive controls also started to be commercially implemented. Meanwhile, in early the 1990s, the robustness of adaptive controllers was addressed.

2.4 POST-1980

In 1985, Stephane Mallat gave wavelets an additional jump-start through his work in digital signal processing. He discovered some relationships between quadrature mirror filters, pyramid algorithms, and orthonormal wavelet bases (more on these later). Inspired in part by these results, Y. Meyer constructed the first non-trivial wavelets. Unlike the Haar wavelets, the Meyer wavelets are continuously differentiable; however they do not have compact support. A couple of years later, Ingrid Daubechies used Mallat's work to construct a set of wavelet orthonormal basis functions that are perhaps the most elegant, and have become the cornerstone of wavelet applications today.

2.4.1 Classical and Modern Control

Control systems are one of the most important science issues. Control systems are found in many types of applications in industry, such as power systems, computer control, Fighter Jets, robotics, weapon systems and many others. Due to the development of civilization and progress, systems will become more complex and traditional controllers cannot become efficient, so different types of controller appeared to meet this progress.

2.4.2 Classical Control

The scope of classical control is limited to single-input and single-output (SISO) system design and its methods are based on frequency response measurement deal with linear systems. The linear system is described by a transfer function model. The most common controllers designed using classical control theories are PID controllers (over 90 percent of applications are using this controller).

2.4.3 Modern Control

On the other hand, modern control deals with state space and its methods are based on time response measurement. The systems under this type of control cover multi-input and multi-output (MIMO) systems and deal with nonlinear systems such as our case study which is magnetic levitation system. Adaptive control and robust control are examples of modern control.

2.4.4 Linear and Nonlinear Systems

The systems can be classified into two types: linear and nonlinear systems. In our life, most of systems are nonlinear.

2.4.4.1 Linear Systems

The linear system is a mathematical model of a system based on the use of linear operations. It exhibits features and properties that are much simpler than, nonlinear systems. Linear systems satisfy the properties of superposition and homogeneity. Linear systems find important applications in automatic control theory, signal processing, and telecommunications.

2.4.4.2 Nonlinear Systems

A nonlinear system is a system where the superposition (Supper position means that if $y_1(t)$ is the response of input$x_1(t)$ and $y_2(t)$ is the response of $x_2(t)$. Then the net response for two inputs is the sum of the responses for two inputs) and homogeneity (homogeneity means if an input scaled by a certain factor produces an output scaled by that same factor) do not apply [1]. Thus, an approximation is used to deal with these systems by converting them to linear systems via linearization; however, this method is used only over specific ranges.

2.4.5 Adaptive Control

An adaptive control system is a branch of modern control that can deal with nonlinear systems and gives the desired performance. It measures a certain performance index (IP) of the control system using the inputs, the states, the outputs and the known disturbances. The adaptation mechanism modifies the parameters of the adjustable controller and/or generates an auxiliary control in order to maintain the performance index of the control system close to a set of given ones.

2.5 Motivation

Magnetic Levitation System is one of the most nonlinear complex systems. As it is known, it has many applications in our life such as high speed trains. In these systems, the traditional controllers such as PID controllers will not meet our performance conditions. So this motivated to design an adaptive controller to control the maglev system and makes the levitation object as stable as possible and meet our demands in performance criteria.

2.5 TRADITIONAL CONTROL VERSUS ADAPTIVE CONTROL

2.5.1 Similarities between Traditional and Adaptive Control

Traditional control started in a mechanical aspect with the development of governors and it has come a long way today. It started with robustness and physical control in view rather than the need of preciseness and accuracy. During its initial days governors were used to help the system maintain its speed in a constant limit pertaining to the physical constrains of the mechanical components. Most of the algorithms developed and one of the most common ones which is used most in the industry even today i.e. PID controller is also implemented in view of prioritizing robustness over accuracy. Although there has been an exponential incline towards accuracy keeping in view of robustness, the gradual improvement of algorithms is still under way and has a long way to go.

On another hand the adaptive control algorithms prioritize accuracy and preciseness over robustness. It works towards correcting the smallest of errors. The comparison being such that the need for stability is being observed in both the traditional and adaptive control algorithms. The attaining of stability is here considered to be a tradeoff in-between robustness accuracy and computational power.

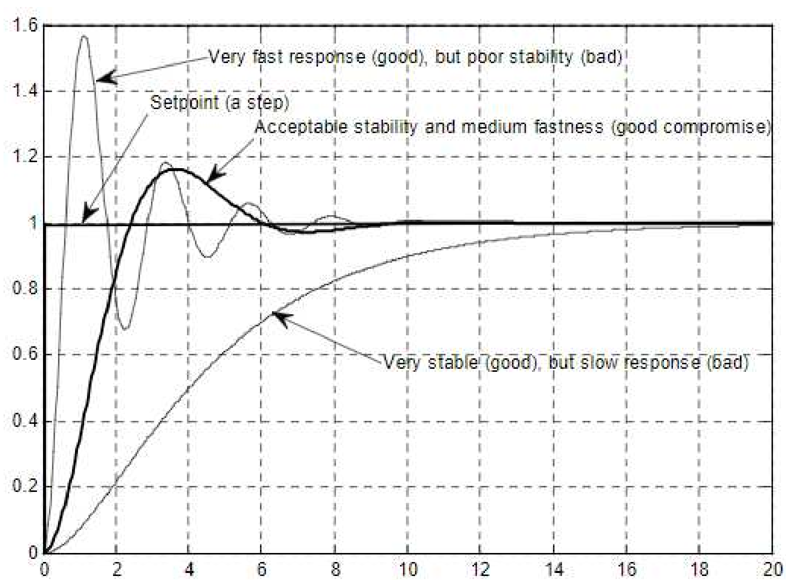
2.5.2 Dissimilarities between Traditional and Adaptive Control

The most interesting dissimilarity between these two kinds of control is the priority towards computation and the priority towards robustness. These both have a lot of variation in these aspects respectively. The traditional control algorithms focus more towards robustness and an easy to use application as compared to the adaptive control algorithms which work towards a crisp response suitable for a complex control system. Both of the types of control algorithms have their own fields of application. Basic algorithms and application prefer a more robust algorithm over a more precise one. While the more complex applications like fighter jets, cars, nuclear reactors and other sensitive control applications seek a more precise control. Adaptive controls are inherently and relatively computationally expensive as compared to the traditional control algorithms.

The fact that an adaptive control is computationally expensive adds many factors such as computation power to solve second order or higher differential equations on every iteration while a traditional algorithm does not need such computation power so it can be implemented on basic microcontrollers. The applications which require a complex algorithm require to satisfy this tradeoff to meet the computational expense of an algorithm of higher accuracy and precision.

2.5.3 Characreristics of PID

PID solely can be explained on the basis of the given curve with various factors representing various parameters causing the curve to stabilize and also for the cause of reduction of settling time , improvement of speed of response.



The PID algorithm is comprising of three different terms represented as follows:

P - Proportional

I - Integrator

D – Differential

2.5.3.1 PROPORTIONAL

The word proportional is self-explanatory on what it does and about its role in the PID control algorithm. It produces an input response in a factored multiple which becomes proportional to the error. It is represented mathematically as

$$P = K_p * \text{Error}$$

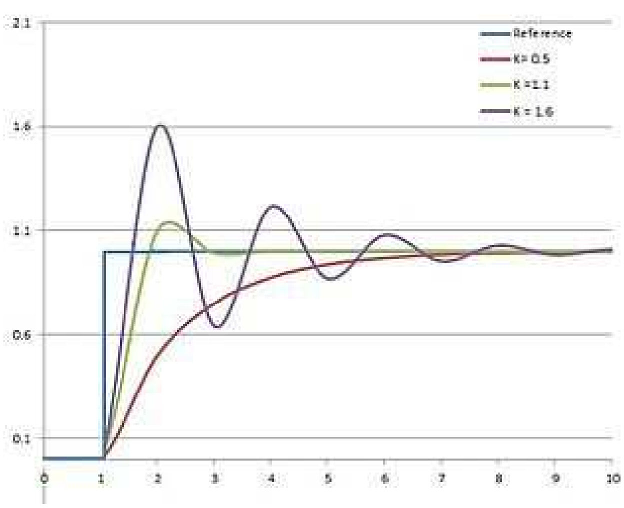
Where,

Error = (reference – current position)

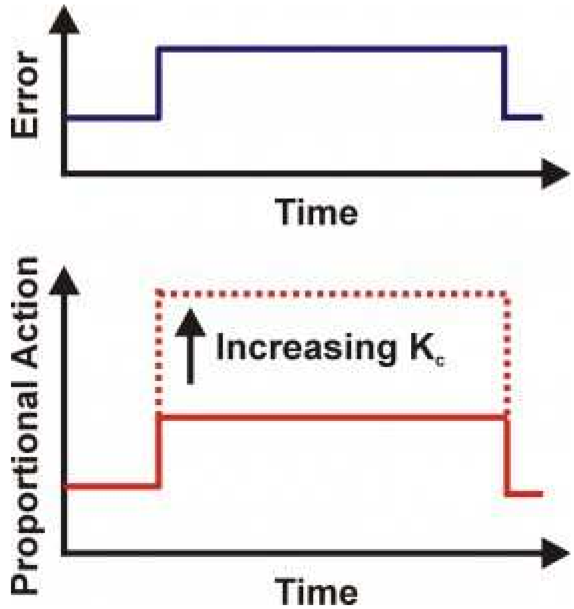
K_p = Proportional constant

P = Proportional term.

The response with the change of each is shown below.



PID Characteristics with varying K_p



2.5.3.2 INTEGRAL

The integral component sums the error term over time. The result is that even a small error term will cause the integral component to increase slowly. The integral response will continually increase over time unless the error is zero, so the effect is to drive the Steady-State error to zero. Steady-State error is the final difference between the process variable and set point. A phenomenon called integral windup results when integral action saturates a controller without the controller driving the error signal toward zero. It is mathematically represented as

$$I = I_{prev} + K_I{*}error{*}\ (T_I/T_S)$$

(OR)

$$I = K_I * (\ error{*}dt)$$

Where,

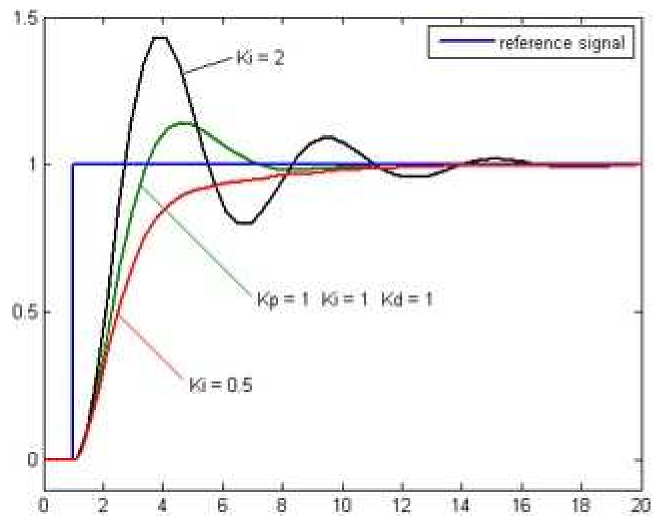
K_I = Integral Constant

T_I = Time over single iteration

T_S = Time over entire process

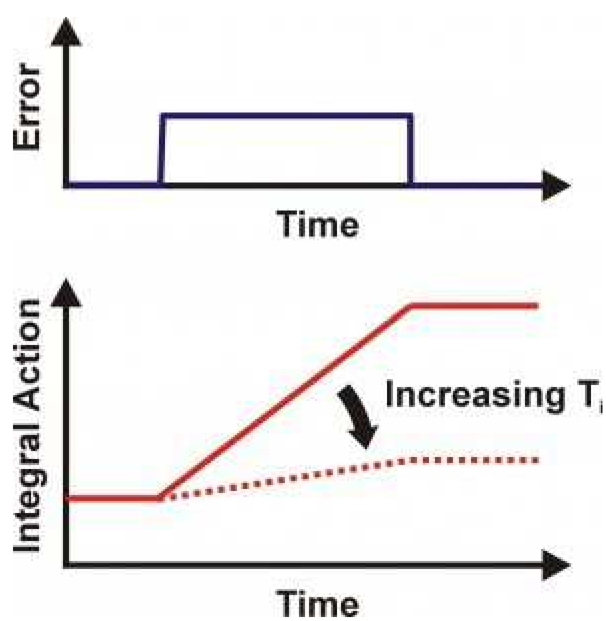
I = Integral term of PID controller

The time based response of variation of the K_I term is shown in the figure below.



PID Characteristics with varying K_I

The variation with change is error for a give K_I term is shown below



This sums up the proportional – integral control of a PID controller. Now we move on to the Derivative control.

2.5.3.2 DIFFERENTIAL

The derivative component causes the output to decrease if the process variable is increasing rapidly. The derivative response is proportional to the rate of change of the process variable. Increasing the derivative time (T_d) parameter will cause the control system to react more strongly to changes in the error term and will increase the speed of the overall control system response. Most practical control systems use very small derivative time (T_d), because the Derivative Response is highly sensitive to noise in the process variable signal. If the sensor feedback signal is noisy or if the control loop rate is too slow, the derivative response can make the control system unstable. The mathematical representation is given by

$$D = K_D * (error_{prev} - error_{current}) / T_I$$

Where,

K_D = Differential constant

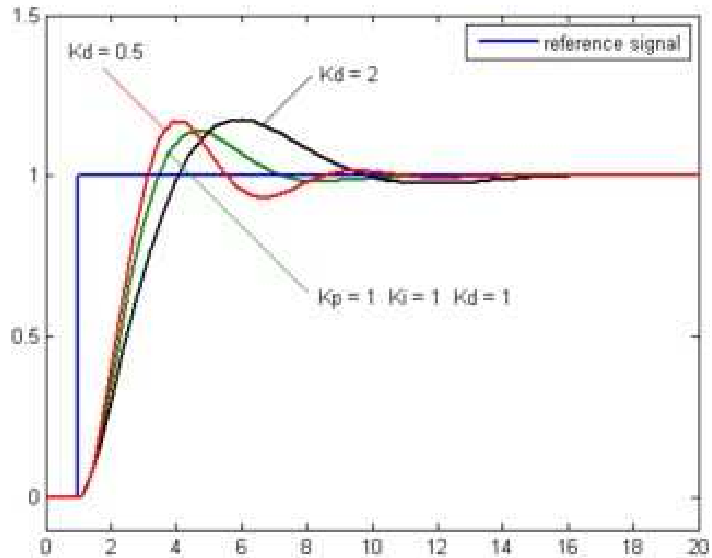
T_I = Time of iteration

$Error_{prev}$ = Previous Error

$Error_{current}$ = Current Error

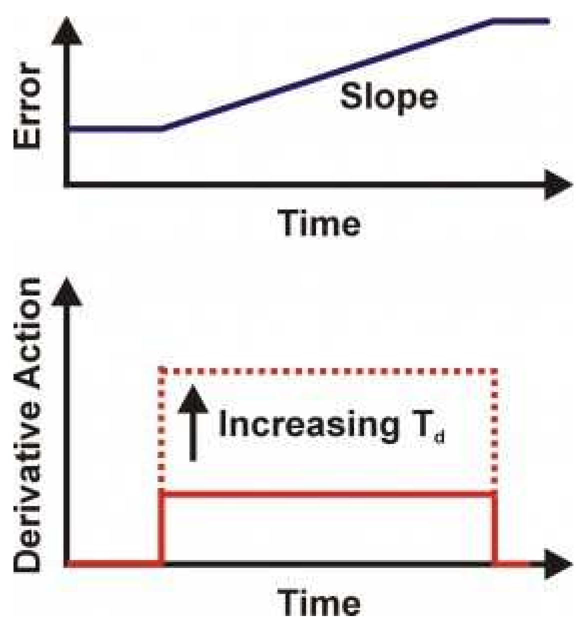
D = Differential term of PID control

The following graph gives the time variant stability control of K_D parameter variation.



PID Characteristics with varying K_D

The variation with change is error for a give K_I term is shown below



So the total PID equation can be summed up as -

$$u_{PID}(t) = k_p e(t) + k_i \int e(t)dt + k_d \frac{d}{dt} e(t)$$

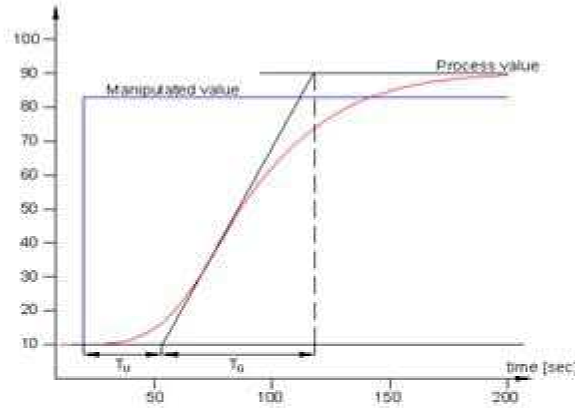
2.5.4 TUNING THE PID CONTROLLER

Before the working of PID controller takes place, it must be tuned to suit with dynamics of the process to be controlled. Designers give the default values for P, I and D terms and these values couldn't give the desired performance and sometimes leads to instability and slow control performances. Different types of tuning methods are developed to tune the PID controllers and require much attention from the operator to select best values of proportional, integral and derivative gains. Some of these are given below.

Trial and Error Method: It is a simple method of PID controller tuning. While system or controller is working, we can tune the controller. In this method, first we have to set Ki and Kd values to zero and increase proportional term (Kp) until system reaches to oscillating behavior. Once it is oscillating, adjust Ki (Integral term) so that oscillations stops and finally adjust D to get fast response.

Process reaction curve technique: It is an open loop tuning technique. It produces response when a step input is applied to the system. Initially, we have to apply some control output to the system manually and have to record response curve.

After that we need to calculate slope, dead time, rise time of the curve and finally substitute these values in P, I and D equations to get the gain values of PID terms.



Process reaction curve

Zeigler-Nichols method: Zeigler-Nichols proposed closed loop methods for tuning the PID controller. Those are continuous cycling method and damped oscillation method. Procedures for both methods are same but oscillation behavior is different. In this, first we have to set the p-controller constant, Kp to a particular value while Ki and Kd values are zero. Proportional gain is increased till system oscillates at constant amplitude.

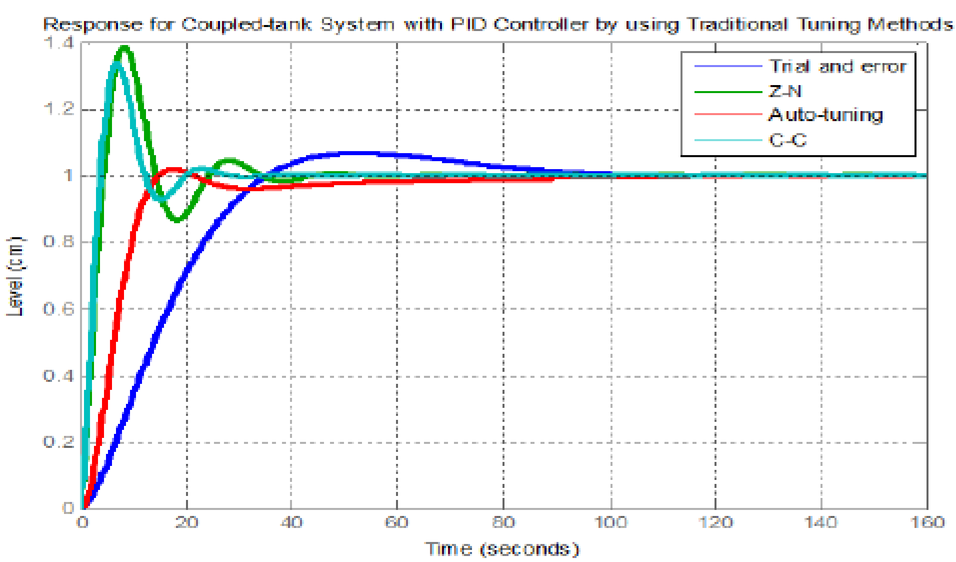
Gain at which system produces constant oscillations is called ultimate gain (Ku) and period of oscillations is called ultimate period (Pc). Once it is reached, we can enter the values of P, I and D in PID controller by Zeigler-Nichols table depends on the controller used like P, PI or PID, as shown below.

	K_c	T_I	T_D
P	$K_u/2$		
PI	$K_u/2.2$	$P_u/1.2$	
PID	$K_u/1.7$	$P_u/2$	$P_u/8$

Zeigler-Nichols table

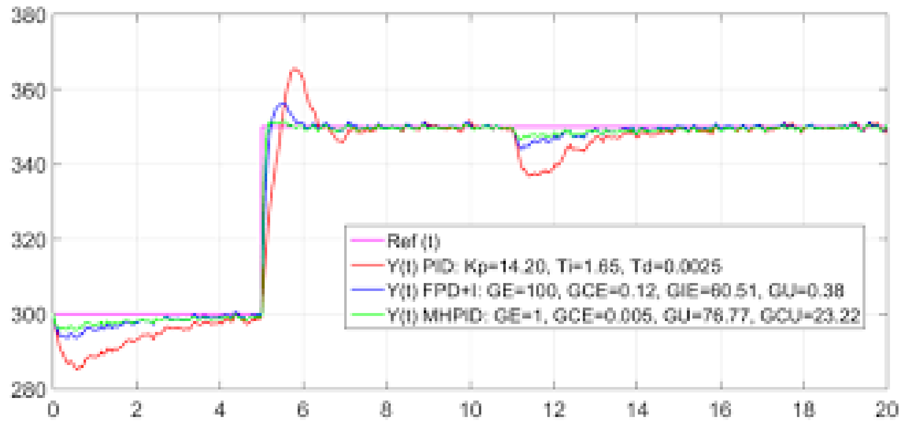
2.5.5 AUTOMATED TUNING OF PID PARAMETERS AND THEIR DISADVANTAGES

There are several methods of auto tuning PID parameters with algorithms such as EVOTUNE, Fuzzy logic, neural control, FLC on Zieger-Nicholas method etc. These are currently being used in the industry and have improved the accuracy although not to a level of paramount succession to the adaptive control method but definitely to a level in which they are good enough for usage in the industries. Auto-tuning routines for PI-PID commercial controllers are a highly desirable characteristic for the industry. With such applications, it is possible to reduce the amount of time required to adjust the controller parameters for a given process, as well as the expertise required for such task. Because of this fact, several commercial products include auto-tuning procedures. The following graph represents the variation in the control for different methods of tuning for the simple PID control.



Although this has proved to be more reliable that the other methods avoiding instability of the system there is not much variation in the settling time as compared to other methods and while accomplishing this , it is neither adaptive nor computationally better than the other adaptive algorithms. This makes the Auto tuning feature in the various kinds of traditional algorithms although fit for usage in the industries but not entirely suitable or in a better way relatively less preferred over an adaptive algorithm.

The following image shows the fuzzy auto tuned PID controller with the sampling intervals and as we can see the computation is highly costly as compared to a normal PID control loop.



This in conclusion shows that in the computational point of view the tradeoff is inclined towards the adaptive control algorithms in case of putting adaptive and tradition control algorithms with auto tune mechanisms against each other.

CHAPTER III

Model Reference Adaptive Control

3.1 WORKING PRINCIPLE

Model reference adaptive control (MRAC), an explicit adaptive strategy, has been very attractive from the very beginning of adaptive control era. The basic idea behind it is to design a closed loop adaptive controller that works on the principle of adjusting the control parameters so that the output of the actual plant tracks the output of a reference model having the same reference input. The basic block diagram of the MRAC system is shown in figure 1.

3.2 BASIC OBJECTIVE

Model Reference Adaptive controller is used to maintain consistent performance of a system in the presence of uncertainty and variations in plant parameters. It is superior to robust control in dealing with uncertainties in constant or slow-varying parameters. As compared to the well-known and simple structured fixed gain PID controllers, adaptive controllers are very effective to handle the unknown parameter variations and environmental changes. It implies that the system is capable of accommodating unpredictable disturbances, whether these disturbances arise within the system or external to it. The basic objective adaptive controller is to maintain a consistent performance of a system in the presence of uncertainty or unknown variation in the plant parameters, which may occur due to non-linear actuators, changes in the operating conditions of the plant and non-satisfactory disturbances acting on the plant.

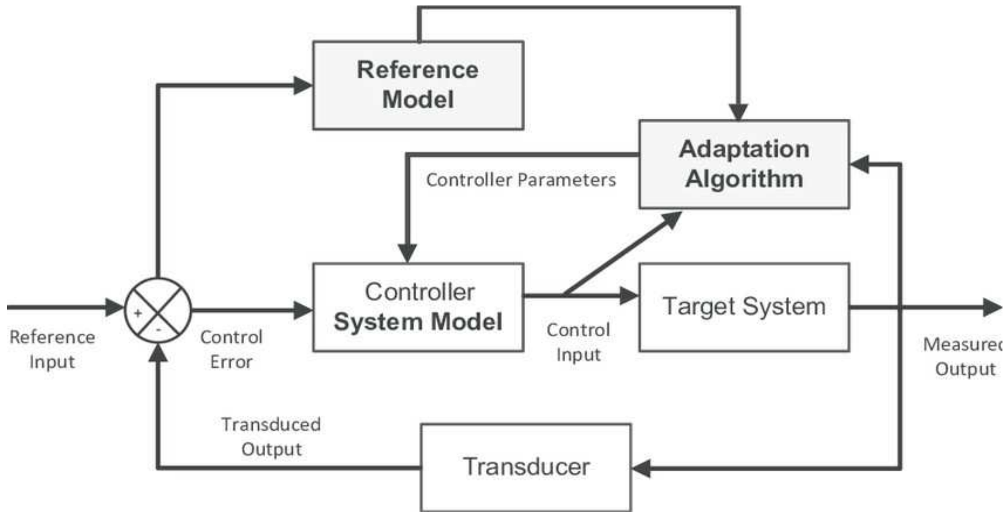


Figure 1: Design of a Model Reference Adaptive Control System

3.3 DIRECT AND INDIRECT ADAPTION ALGORITHM

An adaptive controller is formed by combining an on-line parameter estimator, which provides estimates of unknown parameters at each instant, with a control law that is motivated by the known parameter case. The control law gives rise to two different approaches. In the first approach, referred to as indirect adaptive control, the plant parameters are estimated on-line and used to calculate the controller parameters. This approach has also been referred to as explicit adaptive control because the design is based on an explicit plant model. In the second approach, referred to as direct adaptive control, the plant model is parameterized in terms of the controller parameters that are estimated directly without intermediate calculations involving plant parameter estimates. This approach has also been referred to as implicit adaptive control because the design is based on the estimation of an implicit plant model. In indirect adaptive control, the plant model $P(\theta^*)$ is parameterized with respect to some unknown parameter vector θ^*. An on-line parameter estimator generates an estimate $\theta(t)$ of $\theta*$ at each time t by processing the plant input u and output y. The parameter estimate $\theta(t)$ specifies an estimated plant model characterized by $\hat{P}(\theta(t))$ that for control design purposes is treated as the "true" plant model and is used to calculate the control parameter or gain vector $\theta c(t)$ by solving a certain algebraic equation $\theta c(t) = F(\theta(t))$ at each time t. It is, therefore, clear that with this approach, $C(\theta c(t))$ is designed at each time t to satisfy the performance requirements for the estimated plant model $\hat{P}(\theta(t))$, which may be different from the unknown plant model $P(\theta*)$. Therefore, the principal problem in indirect adaptive control is to choose the class of control laws $C(\theta c)$ and the class of parameter estimators that generate $\theta(t)$ as well as the algebraic equation $\theta c(t) = F(\theta(t))$ so that $C(\theta c(t))$ meets the performance requirements for the plant model $P(\theta*)$ with unknown $\theta*$.

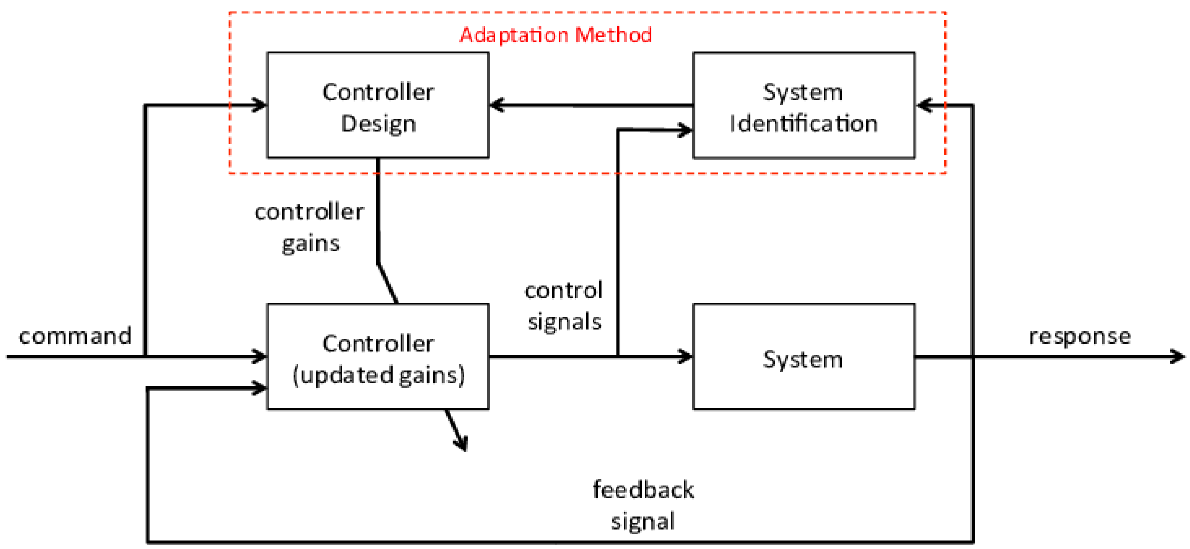


Figure 2: Indirect Adaptive Control

In direct adaptive control, the plant model $P(\theta^*)$ is parameterized in terms of the unknown controller parameter vector θ^*_c, for which $C(\theta^*_c)$ meets the performance requirements, to obtain the plant model $Pc(\theta^*_c)$ with exactly the same input/output characteristics as $P(\theta^*)$.

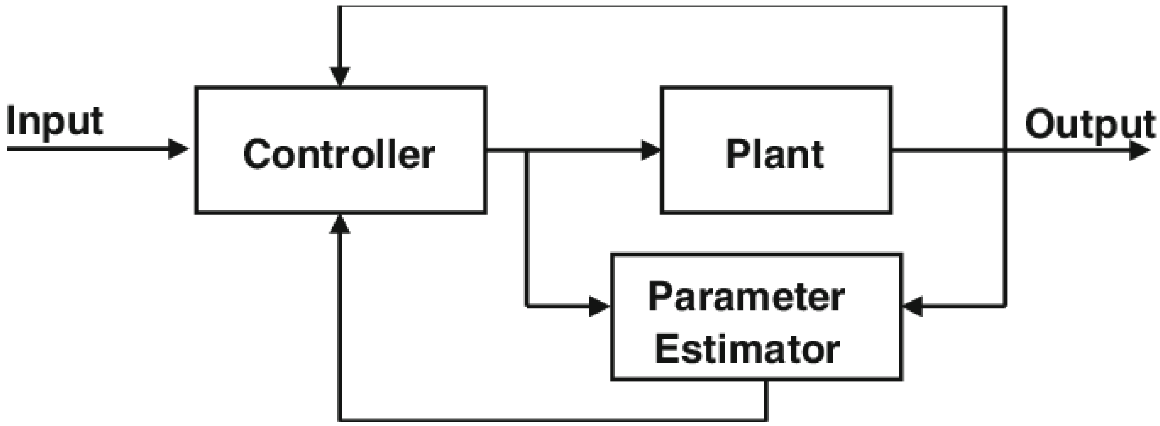


Figure 3: Direct Adaptive Control

Direct adaptive control can be shown to meet the performance requirements, which involve stability and asymptotic tracking, for a minimum-phase plant. It is still not clear how to design direct schemes for non minimum-phase plants. The difficulty arises from the fact that, in general, a convenient (for the purpose of estimation) parameterization of the plant model in terms of the desired controller parameters is not possible for non minimum-phase plant models. Indirect adaptive control, on the other hand, is applicable to both minimum- and non minimum-phase plants. In a nutshell, indirect control algorithm estimates plant parameters and also computes control parameters which rely on convergence of the estimated parameters to their true unknown values while in direct control approach there is no plant parameter estimation but estimates controller parameters only. In this project, we are using Indirect Adaptive Control.

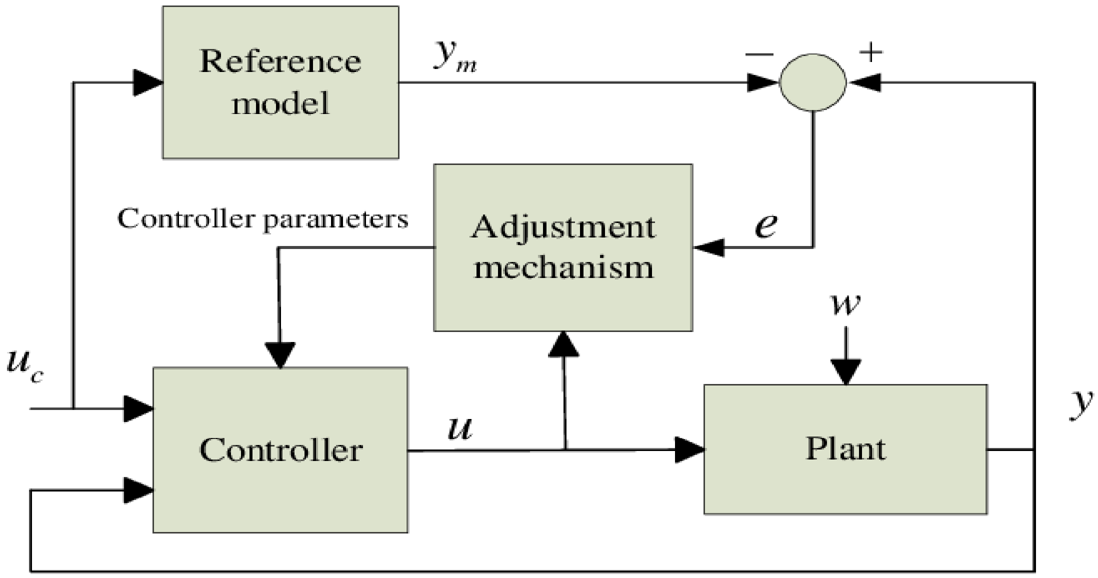


Figure 4: Block diagram of MRAC

3.4 COMPONENTS

A simple block diagram of Model Reference Adaptive Controller is shown in figure 7.

Target System: It has a known structure but unknown parameters.

Reference model: It specifies the ideal (desired) response to the external command, Reference Input.

Controller: It is usually described by a set of adjustable parameters and provides tracking. Its parameters depend on the adaption algorithm. The goal of this part is to consider initial plant condition for calculation purrpose and to achieve overall stability.

Adjusting Mechanism: of the controller is used to adjust the parameters of the controller so that actual plant could track the reference model. There are several mathematical approaches which are used in adjustment mechanism as:

The MIT rule

Lyapunov stability theory

Design of Model Reference Adaptive System (MRAS) based on Lyapunov stability theory

Hyperstability and passivity theory

The error model

Augmented error

A model-following MRAS

In this project, we are using MIT rule.

3.5 MIT RULE

MIT rule was first developed in 1960 by the researchers of MIT, Massachusetts Institute of Technology. It was used to design the autopilot system for aircraft. Now, MIT rule can be used to design a controller with MRAC scheme for any system.

In this rule, a cost function is defined as, where,

e= the error between the outputs of the plant and the model

= The adjustable parameter

It is adjusted in such a manner that the cost function can be minimized to zero. So, the change in the parameter of theta is kept in the direction of the negative gradient of J.

The MIT Rule:

Here, the partial derivative term is called the sensitivity derivative of the system. This term indicates how the error is changing with respect to the parameter θ. is a positive quantity which indicates the adaptation gain of the controller.

Linear feedback from $e = y - y_m$ is not adequate for parameter adjustment.

Process:

Model:

Controller:

Ideal parameters:

The error:

Approximate –

Hence:

Final equation will give us the law for adjusting the parameter θ and the Simulink model is shown in figure 5. It has been seen from simulation results that the response of the plant depends upon the adaptation gain γ'. In some industrial plants, larger values of can cause the instability of the system and selection of this parameter is very critical.

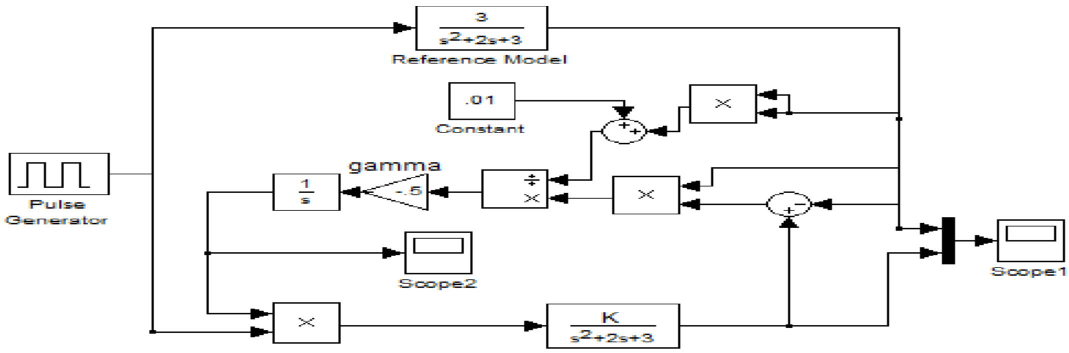


Figure 3: Simulink diagram of Model Reference Adaptive Controller with modified MIT rule

.Normalized algorithm modifies the adaptation law in the following manner,

$$\frac{d\theta}{dt} = \frac{-\gamma \; e \; \varphi}{\alpha + \varphi'\varphi} \tag{9}$$

∂e

Figure 5: Simulink diagram of Model Reference Adaptive Controller with MIT rule.

3.6 SIMULATION AND RESULTS

The MRAC approach is applied to a second order system with MIT rule, whose simulation diagram is shown in figure 3 and the simulation results shown in figure 4 shows the response of actual plant and reference model for different values of adaptation gain γ.

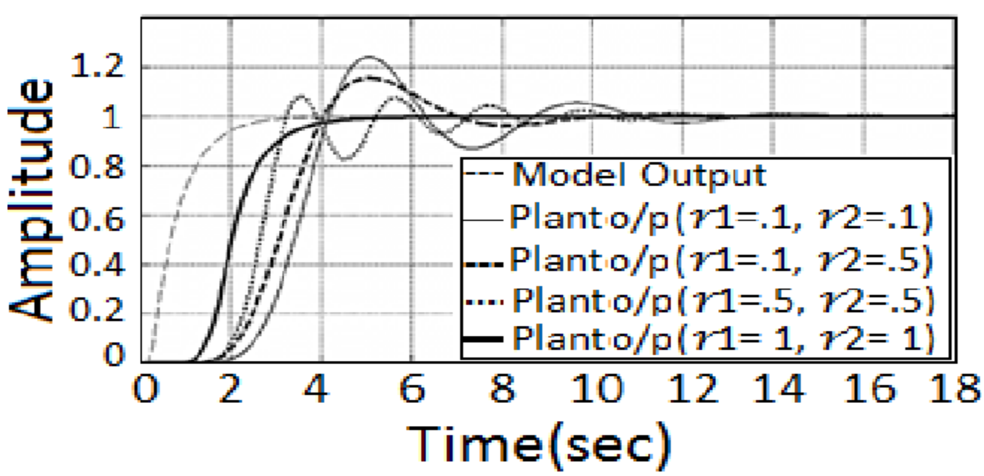


Fig. 5 Response of the system for various values of adaptation gain

Figure 6: Simulink result of Model Reference Adaptive Controller with MIT rule for various adaption gain

3.7 APPLICATIONS

Model Reference Adaptive Systems have been used more and more widely in the last few years to solve various control, parameter identification and state estimation problems. It takes reference from other similar systems and it controls the real system without its dynamic model. Its main applications are in the field of the tracking control, where the plant output is supposed to track a reference trajectory. However, in industrial practice, such as robot control, problems are met which do not correspond to the classical applicationsof model reference adaptive control and few of them are discussed below. Integrated Resilient Aircraft Control project (IRAC) under the NASA aviation Safety program has been continuously working on the MRAC system and its wide applications.

3.7.1 AIRCRAFT CONTROLLING MECHANISM

In current time, Model Reference Adaptive Control (MRAC) is used to control the mechanism of aircraft which can be largely affected by external factors like weather conditions, structural damages or the failure of aircraft components, problems associated with boundary control, which involve control of multiple response variables and many others. Performance evaluation of the suggested scheme(s) is carried out via simulation for pilot commands as well as for gust excitations.

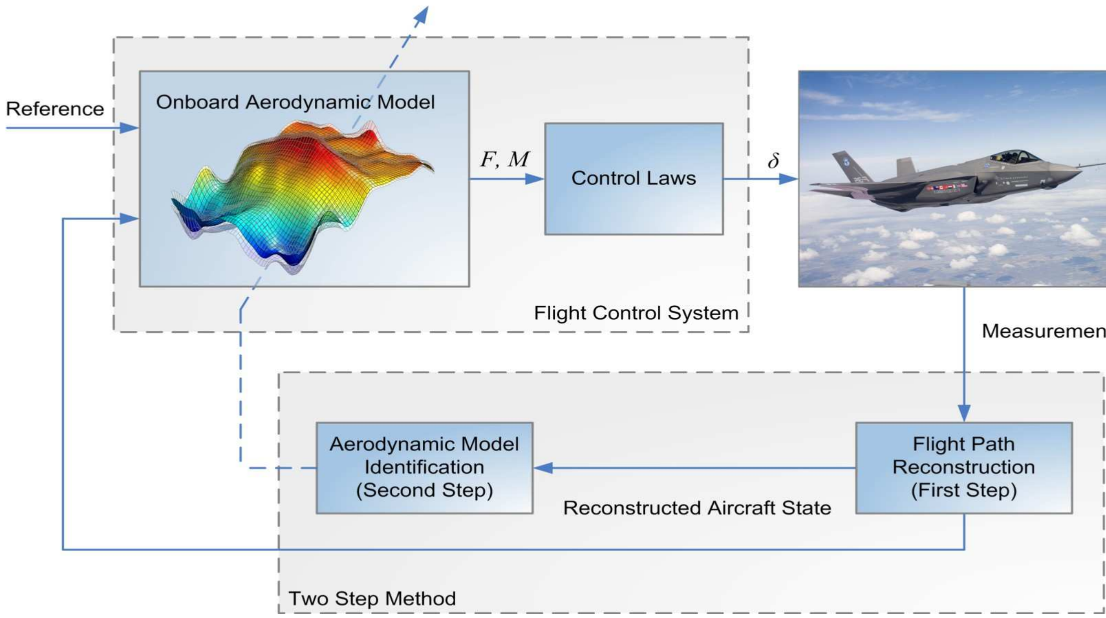


Figure 7: Aircraft model using MRAC for automatic controlling purpose

3.7.2 pH CONTROL EFFECTS OF LAG AND DELAY TIME

A Model Reference Adaptive Control System (MRAC) was used for the pH neutralization of acidic wastewater containing acetic and propionic acids with sodium hydroxide. Buffering changes were made by including sulfuric and common-ion salts. The experimental setup consists of a continuously stirred tank reactor implemented with a pH electrode, a control valve, and an on-line computer. A numerical simulation was made to study the influence of the model parameters and the effects of factors such as lag, delay time, valve dead band, dead zones, short cuts, and presence of dissolved CO2. The tuning methodology and the effects of lag and delay were validated experimentally. For short delays (<4 s) and moderate lags (<5 s), the controller can be tuned easily by adjusting two model parameters (a delay, R, and a gain, βA). Once tuned, the controller has sufficient robustness and adaptive performance against buffering changes and other perturbations. Nevertheless, for long delays (>10 s), the controller has important limitations.

3.7.3 AIRCRAFT ROLL ATTITUDE CONTROL SYSTEM

Flight control is an interesting and technically challenging subject and as the complexity of aircrafts increase, classical methods become unsatisfactory to yield acceptable performance and come to its limits when controllers for Multi-Input Multi-Output (MIMO) systems with high internal coupling are to be designed. An adaptive controller is thus, a controller that can modify its behaviour in response to changes in the dynamics of the plant and the character of the disturbances. The basic objective adaptive controller is to maintain a consistent performance of a system in the presence of uncertainty or unknown variation in the plant parameters, which may occur due to non-linear actuators, changes in the operating conditions of the plant and non-satisfactory disturbances acting on the plant.

3.7.4 MACHINE TOOL

Improvements in CNC machine tools depend on the refinement of adaptive control, which is the automatic monitoring and adjustment of machining conditions in response to variations in operating performance. With a manually controlled machine tool, the operator watches for changes in machining performance (caused, for example, by a dull tool or a harder workpiece) and makes the necessary mechanical adjustments. An essential element of NC and CNC machining, adaptive control is needed to protect the tool, the workpiece, and the machine from damage caused by malfunctions or by unexpected changes in machine behaviour. Adaptive control is also a significant factor in developing unmanned machining techniques. One example of adaptive control monitoring of torque to a machine tool's spindle and servomotors. The control unit of the machine tool is programmed with data defining the minimum and maximum values of torque allowed for the machining operation.

3.7.5 CONTROL SYSTEM

Adaptive control is the capability of the system to modify its own operation to achieve the best possible mode of operation. A general definition of adaptive control implies that an adaptive system must be capable of performing the following functions: providing continuous information about the present state of the system or identifying the process; comparing present system performance to the desired or optimum performance and making a decision to change the system to achieve the defined optimum performance; and initiating a proper modification to drive the control system to the optimum. These three principles—identification, decision, and modification—are inherent in any adaptive system. Dynamic-optimizing control requires the control system to operate in such a way that a specific performance criterion is satisfied.

3.7.6 MODERN DEVELOPMENTS

Different approach like traditional negative feedback control, optimal control, adaptive control, and artificial intelligence can be applied to a system. Traditional feedback control theory makes use of linear ordinary differential equations to analyze problems. The difference between optimal and adaptive control is that the latter must be implemented under conditions of a continuously changing and unpredictable environment; it, therefore, requires sensor measurements of the environment to implement the control strategy.

3.8. LIMITATIONS OF ADAPTIVE CONTROL EFFICIENCY

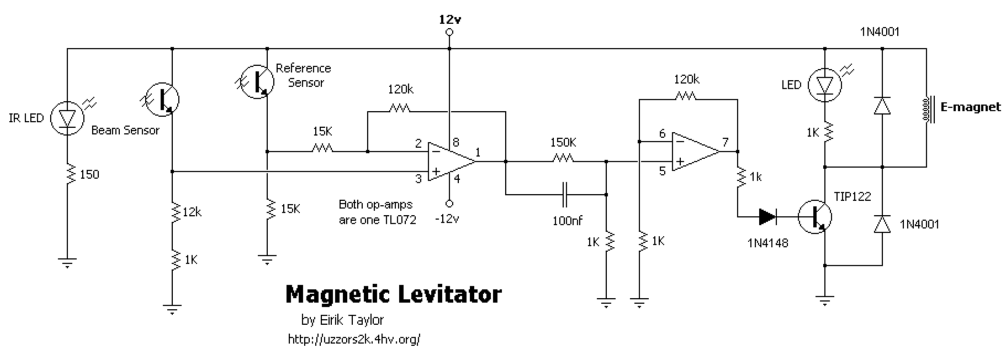
The problem of fundamental performance limitations in adaptive parameter estimation and system identification, occurring in environments where perturbations are present but there is a lack of sufficient excitation. So, we construct a simple yet with a bursting scenario to derive an analytical lower bound on the worst-case peak steady-state error for a wide class of parameter estimation and system identification algorithms. In the absence of any input constraints, arbitrarily small perturbations impose a serious performance limitation, in the sense that the worst-case performance deteriorates proportionally with the size of the parametric uncertainty set.

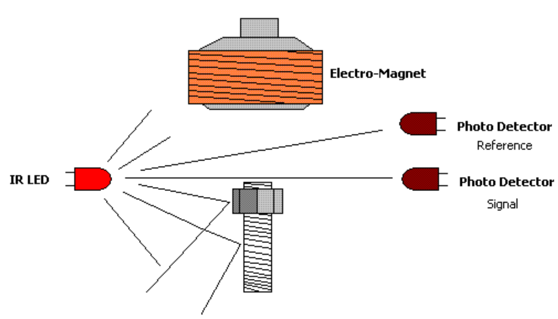
CHAPTER IV

MAGNETIC LEVITATION SYSTEM

4.1 INTRODUCTION

Magnetic fields are actively excluded from superconductors. If a small magnet is brought near a superconductor, it will be repelled because induced super currents will produce mirror images of each pole. If a small permanent magnet is placed above a superconductor, it can be levitated by this repulsive force. Levitation currents in the superconductor produce effective magnetic poles that repel and support the magnet. The black ceramic material in the illustrations is a sample of the yttrium based superconductor. By tapping with a sharp instrument, the suspended magnet can be caused to oscillate or rotate. This motion is found to be damped, and will come to rest in a few seconds.





4.1.1 MATHEMATICAL MODELLING OF MAGNETIC LEVITATION SYSTEM

In this section, the mathematical model of maglev system has been presented. The force actuated by the electromagnet is formulated as

$$F_{mag} =$$

Where (t) denotes the current across the electromagnet, d is the vertical position and C is a constant related to turn ratio and cross sectional area of the electromagnet. The parameters are given in Table1.

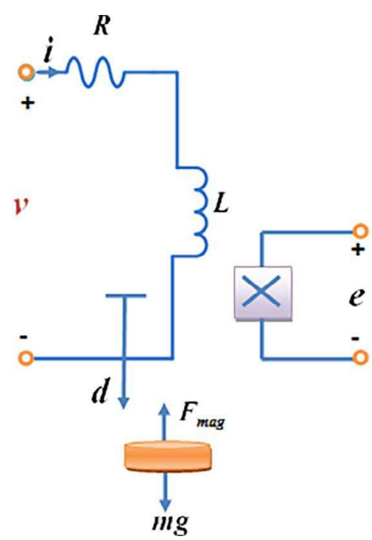


Table 1
Proposed system parameter.

	Parameter	Value	Unit
Sensor	β	$5.64\ \ 10^{4}$	$V.m^{2}$
	γ	0.31	V/A
	α	2.48	V
Operation point	I_0	1	A
	d_0	20	mm
Electromagnet	C	$2.4\ \ 10^{6}$	$Kgm^{5}/s^{2}A$
	R	2	Ω
	L	$15\ \ 10^{3}$	H
	m = M/4	0.02985	kg

Now to balance the force we have,

where m is the mass of the levitating magnet plus one-fourth of the mass of the acrylic plate and g is the is the acceleration due to gravity, In addition, an electrical relation of the voltage supply and the electromagnetic coil can be expressed by

Where R and L are resistance and inductance of the electromagnet respectively. Now consider the following perturbations with respect to the change of them where v_0 is the required equilibrium coil voltage to suspend the levitating plate at d_0. Under this condition the dynamics around operating point () can be linearized as

where is linearization of the system about the equilibrium point.

where V(s) and D(s) denote the Laplace transforms of v(t) and d(t), respectively. The hall sensor used in the apparatus will have an output voltage in the given form.

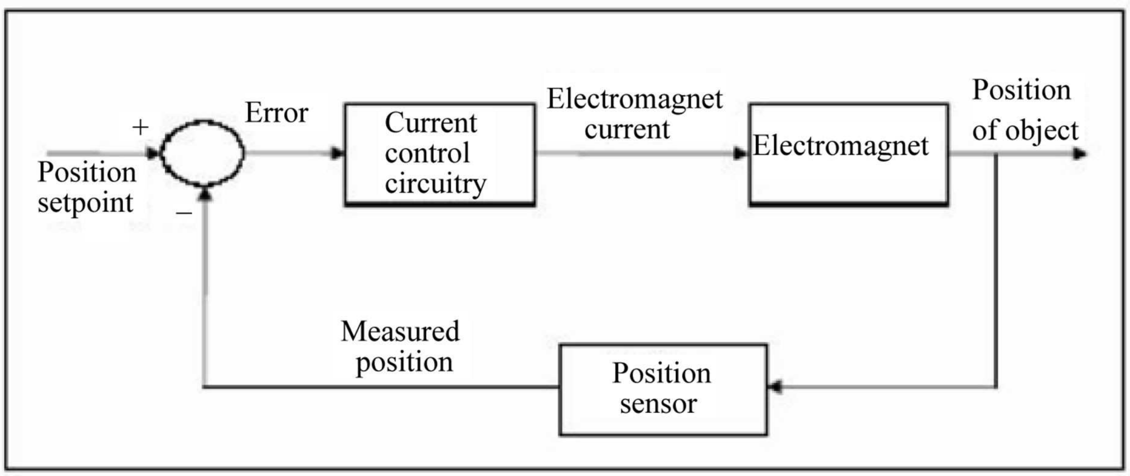
where are constant sensor parameters. A linearization around e(t)= e0 + e results in

where e is the sensor voltage Applying Laplace transform and using I(s) = V(s)/(Ls + R) ,we obtain a relation between the electromagnet voltage V(s) and a sensor voltage perturbation E(s) as follows

This equation can also be represented in the state-space form after applying the required derivatives and the linearized model can be written as

The measured output is also obtained while simplifying with considering the variables as -

The block diagram of a magnetic levitation system is given as –



The magnetic levitation model will be used in the simulation and as well as in the model parameters for the real time plant.

4.2 Applications of Magnetic levitation

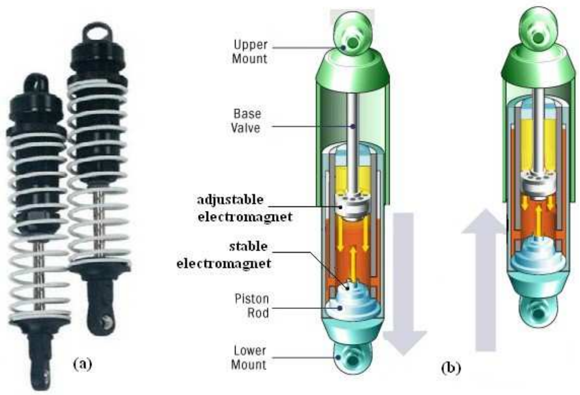
Maglev usages from view point of engineering science can be categorized and summarized as follows:

1. Transportation engineering (magnetically levitated trains, flying cars, or personal rapid transit (PRT), etc.)
2. Environmental engineering (small and huge wind turbines: at home, office, industry, etc.)
3. Aerospace engineering (spacecraft, rocket, etc.)
4. Military weapons engineering (rocket, gun, etc.)

5. nuclear engineering (the centrifuge of nuclear reactor)
6. Civil engineering including building facilities and air conditioning systems (magnetic bearing, elevator, lift, fan, compressor, chiller, pump, gas pump, geothermal heat pumps, etc.)
7. Biomedical engineering (heart pump, etc.)
8. Chemical engineering (analyzing foods and beverages, etc.)
9. Electrical engineering (magnet, etc.)
10. Architectural engineering and interior design engineering including household and administrative appliances (lamp, chair, sofa, bed, washing machine, room, toys (train, levitating spacemen over the space ship, etc.), stationery (pen), etc.)
11. Automotive engineering (car, etc.)
12. Advertising engineering (levitating everything considered inside or above various frames can be selected).

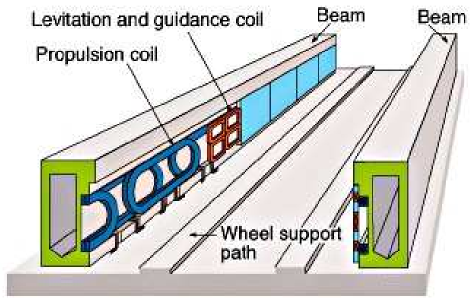
4.2.1 Electromagnetic Suspension (EMS)

The test bed can be used as a platform for control theory and maglev work. The completion of the project demonstrates the feasibility of magnetic levitation for any number of diverse applications. The test bed is capable of levitating a small steel ball at some stable steady-state position. The levitation is accomplished by an electromagnet producing forces to support the ball's weight. A position sensor indicates the ball's vertical position and relays this to a PC based controller board. The control system uses this information to regulate the electromagnetic force on the ball. The system consists essentially of a platform test bed and a PC with a DSP controller board. The test bed contains the electromagnet actuator, optical position sensor, electromagnet PWM power amplifier, and 2 DC power supplies



4.2.2 Magnetically Levitated Trains

Among useful usages of magnetic levitation technologies, the most important usage is in operation of magnetically levitated trains. Maglev trains are undoubtedly the most advanced vehicles currently available to railway industries.
Maglev is the first fundamental innovation in the world of railroad technology since the invention of the railroad. Magnetically levitated train is a highly modern vehicle. Maglev vehicles use noncontact magnetic levitation, guidance, and propulsion systems and have no wheels, axles, and transmission. Contrary to traditional railroad vehicles, there is no direct physical contact between maglev vehicle and its guide way. These vehicles move along magnetic fields that are established between the vehicle and its guide way. Conditions of no mechanical contact and no friction provided by such technology make it feasible to reach higher speeds of travel attributed to such trains. Manned maglev vehicles have recorded speed of travel equal to 518 km/hr. The replacement of mechanical components by wear-free electronics overcomes the technical restrictions of wheel-on-rail technology. Application of magnetically levitated trains has attracted numerous transportation industries through-out the world. Magnetically levitated trains are the most recent advancement in railway engineering specifically in transportation industries. Maglev trains can be conveniently
Considered as a solution for transportation needs of the current time as well as future needs of the world. There is variety of designs for maglev systems and engineers keep revealing new ideas about such systems.



4.2.3 Levitated Launch of Rockets

A magnetic levitation track is up and running at NASA's Marshall Space Flight Center in Huntsville, Ala, USA. The experimental track is installed inside a high-bay facility at the Marshall Center. Marshall's Advanced Space Transportation Program is developing magnetic levitation or Maglev technologies that could give a space launch vehicle a "running start" to break free from Earth's gravity. A Maglev launch system would use magnetic fields to levitate and accelerate a vehicle along a track at speeds up to 600 mph. The vehicle would shift to rocket engines for launch to orbit. Maglev systems could dramatically reduce the cost of getting to space because they are powered by electricity, an inexpensive energy source that stays on the ground—unlike rocket fuel that adds weight and cost to a launch vehicle.

The Foster-Miller experimental track accelerates a carrier to 57 mph at its peak traveling 22 feet in 1/4 second, the equivalent of 10 times the acceleration of gravity. The tabletop track is 44 feet long, with 22 feet of powered acceleration and 22 feet of passive braking. A 10-pound carrier with permanent magnets on its sides swiftly glides by copper coils, producing a levitation force. The track uses a linear synchronous motor, which means the track is synchronized to turn the coils on just before the carrier comes in contact with them, and off once the carrier passes. Sensors are positioned on the side of the track to determine the carrier's position so the appropriate drive coils can be energized. Engineers are conducting tests on the indoor track and a 50-foot outdoor Maglev track installed at Marshall last September by NASA and industry partner PRT Advanced Maglev Systems

Inc. of Park Forest, Ill. The testing is expected to help engineers better understand Maglev vehicle dynamics, the interface between a carrier and its launch vehicle, and how to separate the vehicle from the carrier for launch. Future work on large systems will be led by NASA's Kennedy Space Center, Fla, USA. Rockets of the future might be launched using a magnetic levitation (Maglev) launch track similar to the test track recently built at NASA's Marshall Space Flight Center in Huntsville, Ala, USA

The electromagnetic catapault system is shown below

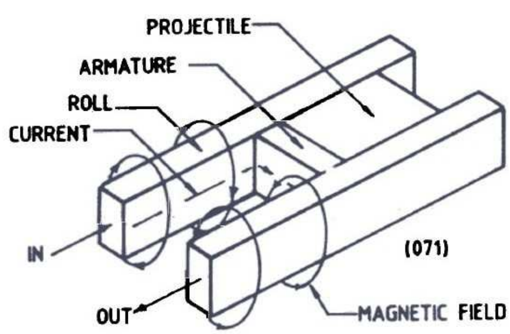


Figure 1. Basic configuration of the railgun.

CHAPTER V

SIMULATION OF PID AND MRAC ON MAGLEV SYSTEM

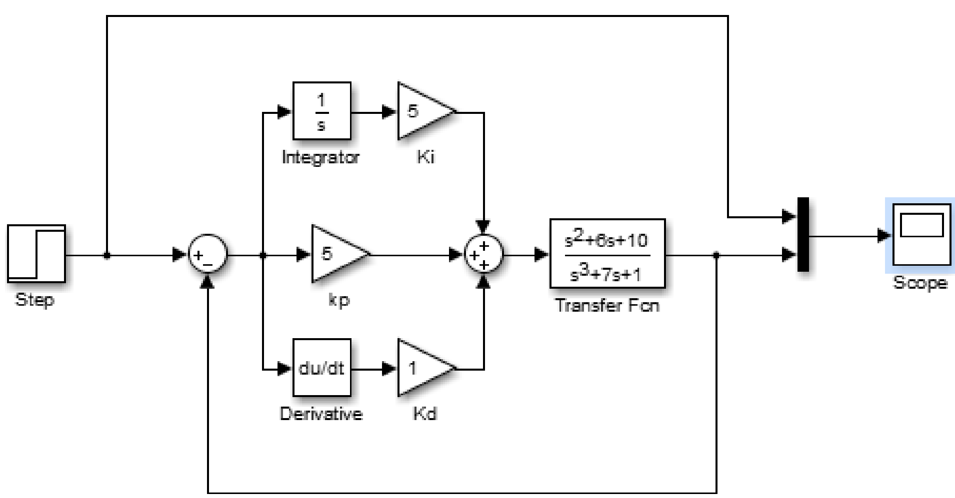
5.1 INTRODUCTION

We are looking to implement both the types of control on the same system so as to estimate and visualize the results based on a certain benchmark with no variation in any other parameters except the change in control algorithms. The main reason behind comparing these two forms of controllers is that each one represents a different form of controller. PID represents a traditional and computationally inexpensive, robust but a relatively less accurate controller while MRAC represents an adaptive controller which is a relatively more accurate, computationally expensive and a relatively non-robust controller. This will provide us with an ability to perform a choice for a tradeoff in-between robustness and the computation power required. This also provides us a strong base for a chance to have a look into a form of hybrid controller which provides parameters which are the best of both the controllers having their best characteristics instilled into the newly formed hybrid controller.

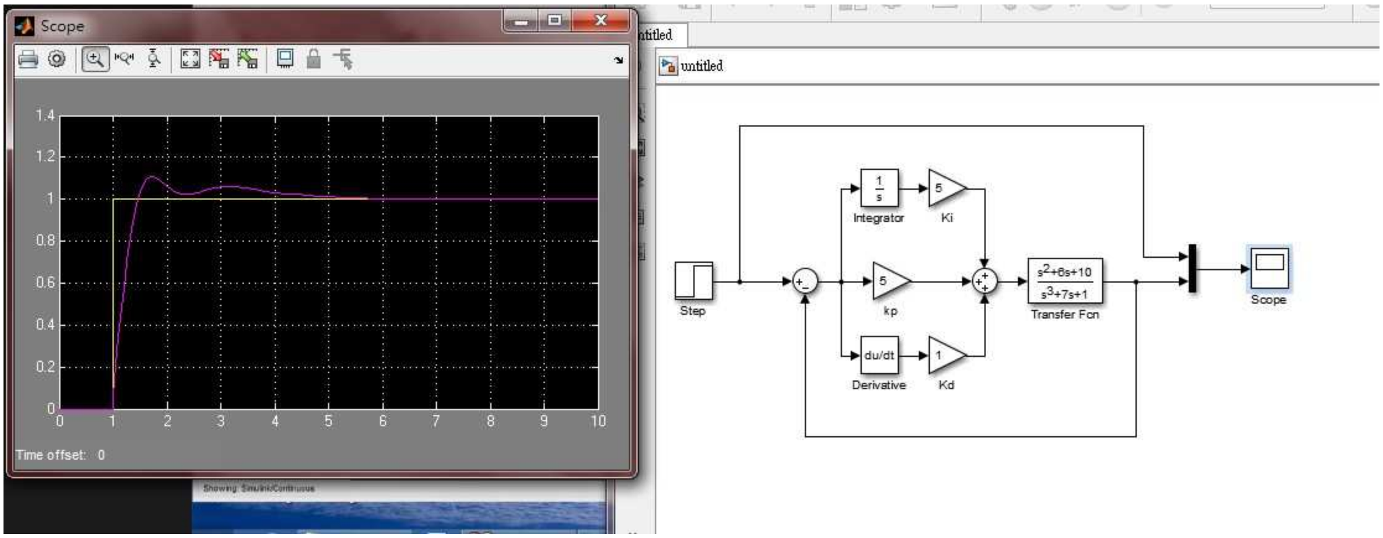
With the help of Simulink we used the block parameters and derived two methods to simulate the MRAC control algorithm. We designed the algorithm from scratch using no blocks with internal code processing or transfer function, and another one with internal processing which looks less complex than the one created from the basic elements. Both of these were implemented to see the difference caused by the parameter and estimation used by the ode45 function which is a default function used by Simulink to process and evaluate differential equations. In the following paragraphs design of each component set has been individually explained.

5.2 PID SIMULATION

The following shows the implementation of the PID control algorithm on the modeled magnetic levitation system. The PID output has been tuned with a trial and error method. The PID as said above symbolized a trademark control algorithms as the most robust, industrial use, easy to implement control algorithm there exists today in the industries. This makes it one of the most important control algorithms that we are taught. It is because of this that most of its important disadvantages are often overlooked as the robustness and simplicity make up for the lack of accuracy and precision in most of the cases but not in all of them. The PID algorithm was implemented in Simulink. The following shown is the block diagram of the same –



This process consists of PID implementation with a transfer function providing input and output and acting as a real time plant.



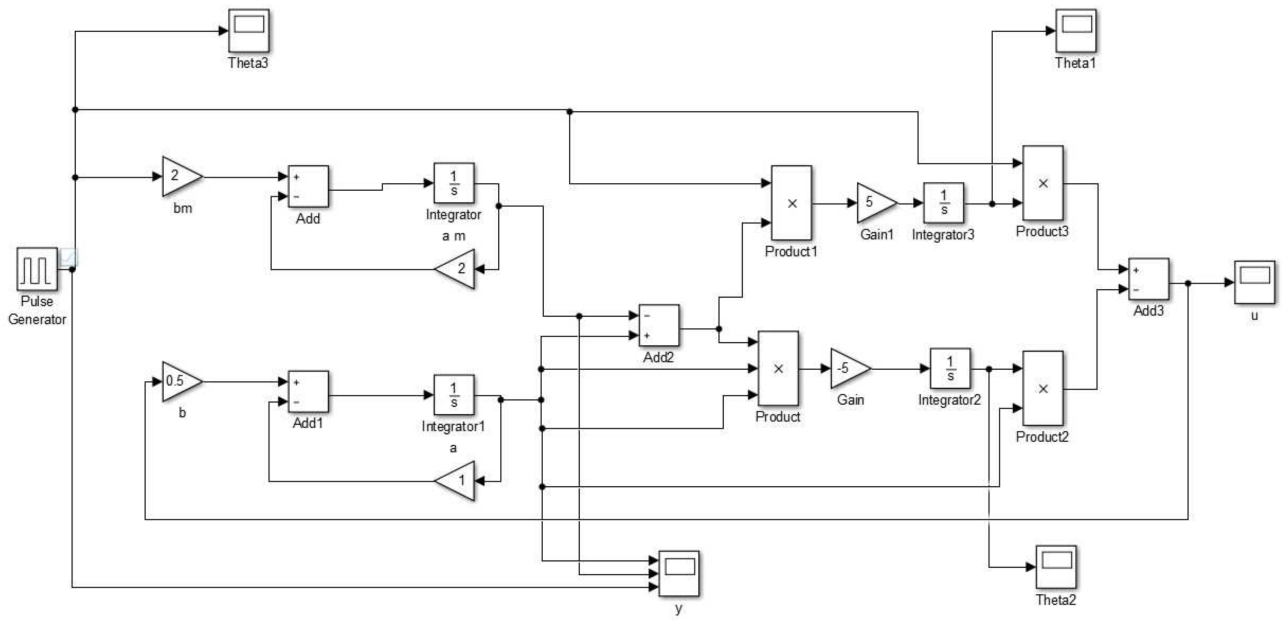
The above image shows the output with respect to the block diagram and input of step input. As we can see although it is computationally very inexpensive the stability of the system is not the best. We work towards this in the implementation of the MRAC control algorithm.

5.3 MRAC IMPLEMENTATION

MRAC was implemented on MATLAB Simulink as well. Implementation of MRAC is mainly to verify the accuracy and stability of the system. We also paid close attention to the error and its variation with respect to time and input. The figure shows both ways of implementing a MRAC control algorithm. It can be done from basic elements forming blocks and then connecting all of them together.

5.3.1 IMPLEMENTATION USING BASIC ELEMENTS

The following diagram shows the implementation of MRAC on a magnetic levitation system in MATLAB Simulink using only basic elements. This give an insight into what makes each element when we simulate it using the transfer function and solve it using various other functions such as ode45.



5.3.2 IMPLEMENTATION USING TRANSFER FUNCTION ELEMENTS

The following diagram shows the implementation of MRAC on a magnetic levitation system in MATLAB Simulink using all the complex elements. This give an overview on what makes the system work entirely when we simulate it using the transfer function and solve it using various other functions such as ode45. This method of visualization proves to be a much easier and a faster way to realize a control algorithm.

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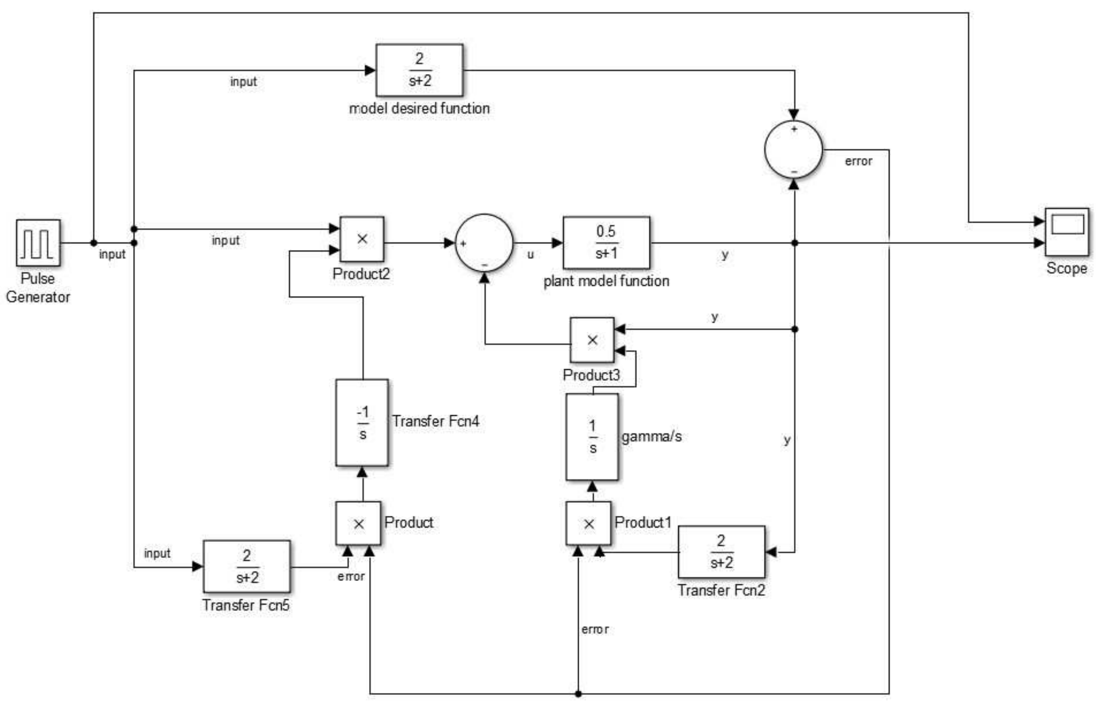


This is visualized keeping in mind the realizations of the equations. The Laplace transform and visualization in the Laplace domain makes it easier to design and put down elements. Hence, when designing, in view of simplicity the following equations were converted into their Laplace domain and then realized.

$$\frac{d\theta_1}{dt} = -\gamma\left(\frac{a_m}{p + a_m}u_c\right)e \qquad \frac{d\theta_2}{dt} = -\gamma\left(\frac{a_m}{p + a_m}y\right)e$$

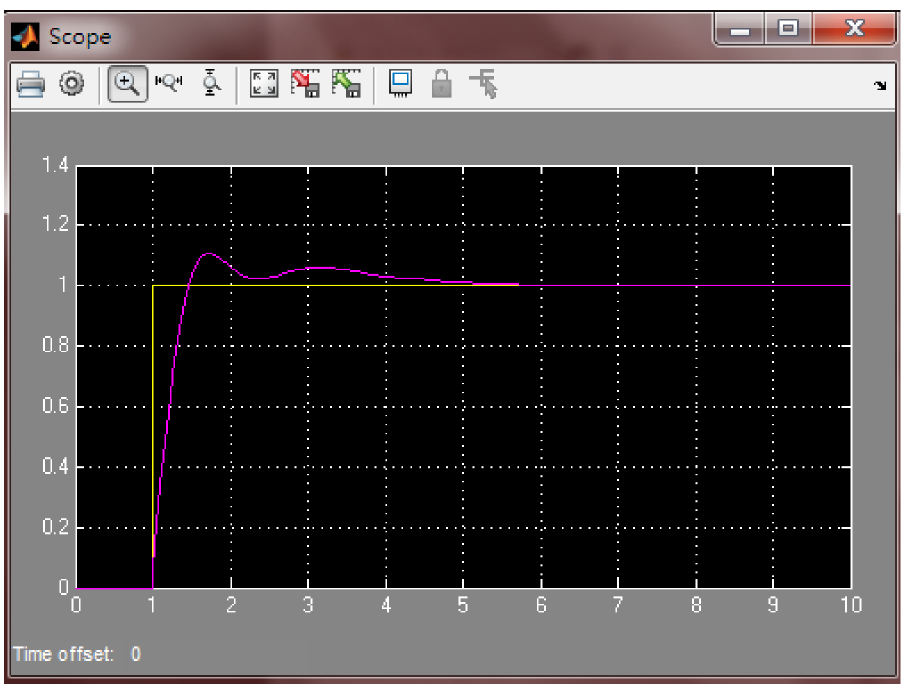
$$y = \frac{b\theta_1}{p + a + b\theta_2} u_c \qquad p = \frac{d\ xt}{dt}$$

CHAPTER VI

RESULTS AND DISCUSSION

CASE I: FOR PID CONTROL OF MAGLEV SYSTEM

The following graph shows the output of the PID control system on a magnetic levitation plant with optimum parameters for the best settling time. In this a we can see the minimum amount of time for a perfect settling will be at least 6 iterations which is way too long until which in the real life complex situations some other variation or another event would also take place which would cause the change in reference point.

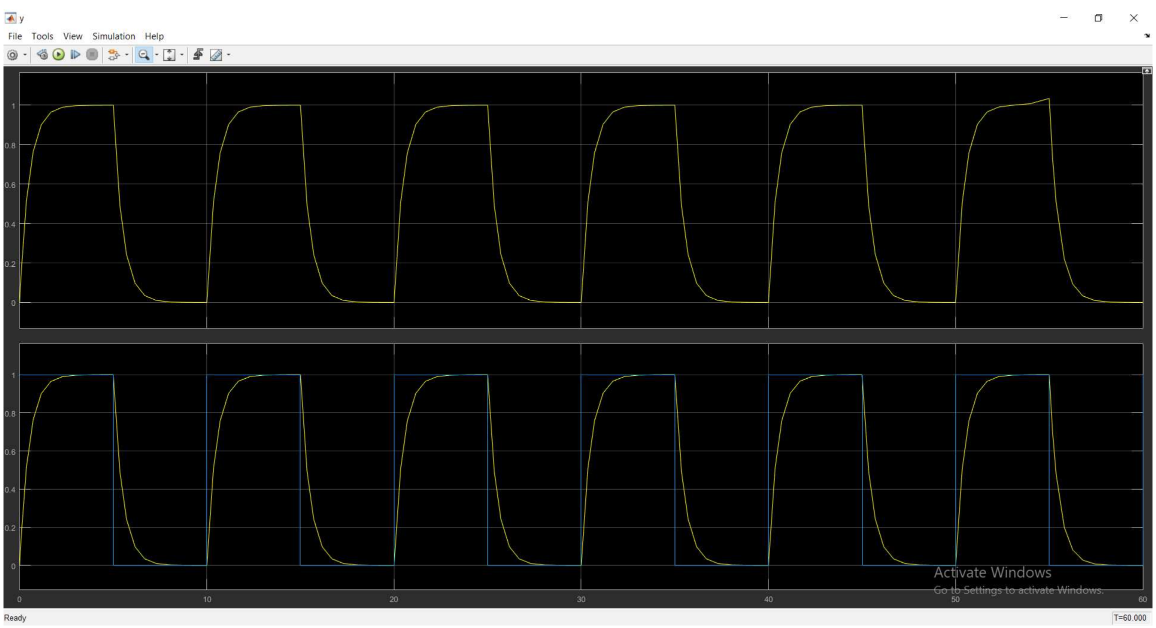


So from this we can conclude that although robust, the only factor which makes it such a widely used control algorithm is the robustness and simplicity in usage.

These factors overshadow the disadvantages and compensate them so as to make this controller the best in use. Although good for use in industries where the priority towards accuracy is not present but towards robustness is.

CASE II : FOR MRAC CONTROL OF MAGLEV SYSTEM

The MRAC control shows the absolute settling time in a lesser iterative step as compared in relative to the PID controller and with a higher accuracy. The only down point in the characteristics of the MRAC controller is the requirement of higher computational power as compared to the traditional PID controller.



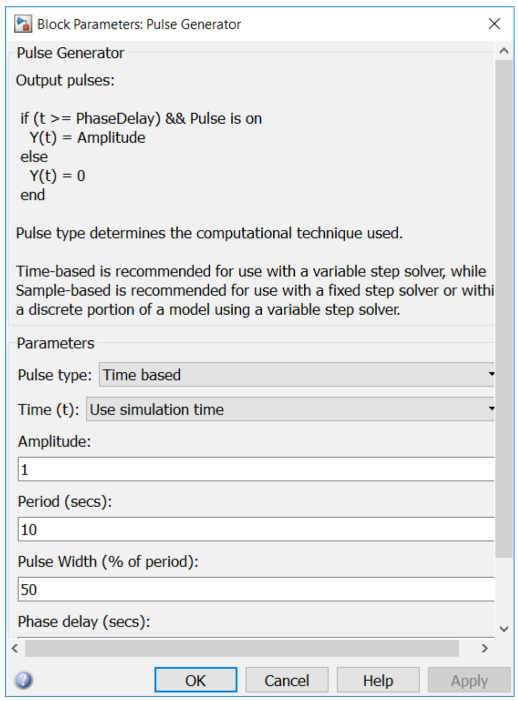
PWM duration – 10 seconds

Pulse Width – 50%

Duration of pulse – 50% * 10secs = 5 seconds

The above graph shows the response for a pulse generator with 50% pwm setting. The setting of the pulse generator is shown below. Which means that for a 50% pwm , the half wave last only for 5 seconds and the algorithm is able to reach the absolute settling point in less than 3 seconds which is in comparison to PID less than half the time PID algorithm takes.

From graph we can infer that it takes less than half the time for the response to reach stability. So we can conclude that it takes ~ 2.5secs.



This compels us to think about the possibility of the implementation of MRAC on industrial application as the usages and advantages of this are limitless. Lastly, it also shows us that the possibility of a hybrid controller of both MRAC and PID controller would give us best characteristics of the both and negates their disadvantages all by themselves. Thus leading to a perfect controller with robustness, computation, efficiency and accuracy as well.

CHAPTER VII

CONCLUSION AND FUTURE SCOPE

7.1 CONCLUSIONS

The conclusions pertaining to this thesis can be broadly classified into 3 broad sections.

I. Fault detection and classification using Wavelet transform:

Since any fault in transmission line results in high frequency components, therefore frequency domain approach has been resorted to detect and classify the faults based on wavelet transform. It is seen that such frequency domain approach is immune from the problems related to fault inception angle and fault impedance as in case of conventional time domain approach.

II. Fault location using Wavelet-ANFIS approach:

The adaptive neuro fuzzy inference system has been used to incorporated the summed wavelet coefficients for different faults for fault location.

III. Monte Carlo Simulation for error analysis:

Since the transmission line faults are random in nature, therefore Monte Carlo Simulation has been employed to created different faults and then wavelet-ANFIS approach has been used for fault location. Then error analysis has been done based on Chi-Square test and results prove the efficacy of the proposed approach.

7.2 FUTURE SCOPE

This results show that wavelets has strong capability to extract important features embedded in power system current and voltage signals even when the features are very weak(ex: high impedance fault). Besides fault classification and location using combined fuzzy, interpolation technique. Stockwell (S) transform can also be applied to obtain a new fault location, classification algorithm, especially for some transient-related problems where Fourier transform may not be sufficient, wavelets may also be used in combination with other fault location technique such as the traveling wave protection. Real-Time implementation for online applications may be proposed in future.

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