Modeling and Simulation of Magnetic Levitation System

By

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FINAL REPORT

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Electrical & Electronics Engineering Programme
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Approved:

A.P. Dr. Irraivan Elamvazuthi
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

September 2011

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 herein have not been undertaken or done by unspecified sources or persons.

Muhammad Haris Fadhullah Bin Badrul Hisham

ABSTRACT

Overcoming the grip of the Earth's gravity has been a high-demand in current technology. Through work of engineers and scientist, human has found many ways to levitate a variety of objects to be applied in the field of mechanical and transportation. Magnetic levitation (Maglev) is a way of using electromagnetic fields to levitate objects without any contact with other material. However, magnetic levitation system is unstable and non-linear. This paper presents the mathematical modeling of the magnetic levitation system. Since magnetic levitation system is a non-linear system, it is controlled using Proportional Integral Derivative (PID) controller and Fuzzy Logic controller. The PID, Fuzzy Logic and Fuzzy-PID control techniques will be simulated and compared to determine which one of them give the best control performance to the system.

ACKNOWLEDGEMENTS

First and foremost, I would like to express my appreciation to my project supervisor, Associate Professor Dr. Irraivan Elamvazuthi for his valuable input and guidance throughout the course of this project.

I would also like to express gratitude to Electrical and Electronics Engineering Department of Universiti Teknologi PETRONAS (UTP) for providing this chance to undertake this remarkable final year project.

Next, I would like to thank the Final Year Project (FYP) committee for arranging various seminars as support and knowledge to assist the students. Thanks to all lecturers and technicians from UTP especially Mr. Azhar Zainal Abidin who had provided untiring guidance and help throughout the period of the project.

Finally, I would like to apologize if any party was inadvertently excluded from being mentioned above and I would like to thank all parties that were involved in making this project a success. Thank you.

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ABBREVIATIONS

FIS	Fuzzy Inference System
FLC	Fuzzy Logic controller
FYP	Final Year Project
IEEE	Institute of Electrical & Electronics Engineers
Maglev	Magnetic Levitation
PID	Proportional Integral Derivative
UTP	Universiti Teknologi PETRONAS

CHAPTER 1

PROJECT BACKGROUND

1.1 Background of Study

Magnetic levitation (Maglev) systems are electromechanical devices that suspend ferromagnetic materials using electromagnetism. Maglev technology has been receiving increasing attention since it eliminates energy losses due to friction. Due to friction reduction, maglev systems have wide engineering applications such as magnetic bearings, high-precision positioning platforms, aerospace shuttles, and fast maglev trains. The most popular examples of Magnetic Levitation are the levitation of the steel ball as shown in Figure 1 and the object that attached with ferromagnetic materials. Without a good control system, the ball cannot be levitated in a stable position. So PID and Fuzzy Logic controller will be implemented to control the position of the levitated object since Magnetic Levitation System is an unstable system.

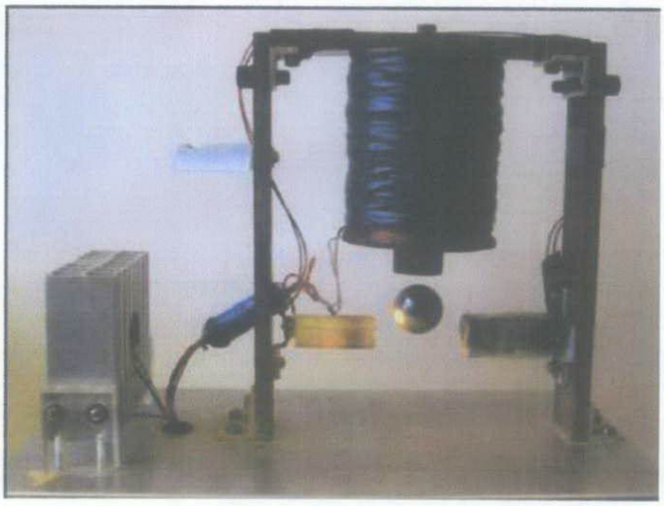


Figure 1: Magnetic Levitation of Steel Ball

1.2 Problem Statement

They are many problems faced by the mankind regarding the effect of the natural gravity of the earth, which some of the material on this earth cannot be controlled because it is affected by the gravitational force. That's why Magnetic Levitation System is unstable and non-linear. In order to avoid this difficulty, this project comes where the control system is implemented in MATLAB using PID and Fuzzy Logic and Fuzzy-PID controller. As a result, the non-linear system will become a linear system in such a way that the ball will be levitated stably. Hence, the PID, Fuzzy Logic and Fuzzy-PID will be compared to determine which one of them giving the best control performance to the system.

1.3 The Relevancy of the Project

In general, magnetic levitation systems have been growingly used for industrial application. However, the magnetic levitation system that has been used has a limitation where the system is unstable and non-linear. The project will provide the significant solution to the problem by performing control system from the MATLAB which will act as the simulator of the system. This project also will be the pioneer for this field of study in Universiti Teknologi PETRONAS since there are no module and case study about the magnetic levitation system. Hence, the project can help the students to appreciate and understands the benefit of system. So no wonder this project can provide many benefits to the engineering students and should be taken into consideration by the Board of Electrical and Electronics Engineering of UTP to implement this project as the laboratory purposes for Control System subjects and with further studies, the integration with magnetic levitation kit will be a good achievement.

1.4 Objective

The objectives of the project are:

i. To develop the mathematical equation of the MagLev model
ii. Simulate the system using MATLAB using PID, Fuzzy Logic and Fuzzy-PID controllers
iii. To compare each method to determine which one of them gives the best control performance
iv. To investigate the fundamental principles of electrical and electronics engineering such as electromagnetism and Fuzzy Logic.

1.5 Scope of Study

The scopes of study for this project are:

1. Investigate the fundamental of the electromagnetism

- Explains how magnetic field is produced by an electric current form of circles. This current flow can be control to the position of the levitated ball on the air.

2. Studies of differential equation modeling theory

- It is the method where the mathematical equation can be represented as plant model.

3. Studies of Fuzzy Logic controller

- Fuzzy Logic controller has not been taught in course in UTP. So within this project, the student is expected to get used with this control technique and use it to control the MagLev system.

1.6 Feasibility of the Project within the Scope and Time frame

This project can be completed within the range of time allocated by the coordinator which is until the final semester (FYP II). All the simulation works can be done along with the documentation works.

CHAPTER 2

LITERATURE REVIEW

2.1 Magnetic Levitation System

Magnetic levitation not only present intricate problems for control engineering research, but also have many relevant applications such as high-speed transportation systems and high precision bearings. From an educational viewpoint, this process is highly motivating and suitable for laboratory experiments and classroom demonstrations, as reported in the engineering education literature [1]-[8]. The (electro) magnetic levitation system is a mechatronic system accepted both for the specific mechatronic area [8] and for other engineering fields, as mentioned in numerous references [9], [10], [11]. At the same time, the magnetic levitation system is a recommended subject for the academic curricula in mechatronic study programs, due to the synergic integration of the sensorial elements, the control subsystem and the actuating subsystem [12], [13].

Magnetic levitation is becoming widely applicable in magnetic bearings, high-speed ground transportation, vibration isolation, etc., [19]. For example, magnetic bearings support radial and thrust loads in rotating machinery. In addition, magnetic suspension generates levitation action in rectilinear motion devices such as high-speed ground transportation systems. Magnetic levitation is immensely beneficial in the aforementioned rotary and rectilinear devices as it yields a non-contact support, without lubrication, thus eliminating friction. All practical magnetic levitation systems are inherently open-loop unstable and rely on feedback control for producing the desired levitation action.

The magnetic levitation system is considered in the current analysis is built of a ferromagnetic ball suspended in a voltage-controlled magnetic field. Figure 2 shows the diagram of the system. The mechatronic system is composed of the following subsystems:

- The electromagnetic actuator represented by the coil 1 (a ferromagnetic core coil);
- The position sensor, determining the position of the metallic ball 2 which is sustained with respect to the coil;
- Electrical circuits for power supply, amplification, control, etc.

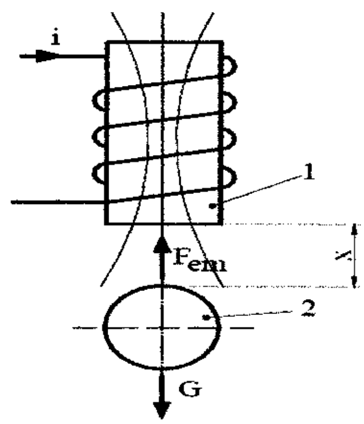


Figure 2: Diagram of the Magnetic Levitation System

The ferromagnetic ball bears the influence of two forces:

- The field gravity “G”,
- The electromagnetic sustentation force F_{em} produced by the electromagnetic field generated in the coil 1.

One can define the equilibrium based on the known basic laws.

The ferromagnetic ball has two degrees of freedom. The analysis envisages only the translation movement performed in the vertical plane, while neglecting the rotation of the ball around its own axis. The goal of the designed system consists in maintaining the ball at a reference level that is preset [15].

A schematic diagram of the single-axis magnetic levitation system with principal components is depicted in Figure 3. The applied control is voltage, which is converted into a current via the driver within the mechanical unit. The current passes through an electromagnet which creates the corresponding magnetic field in its vicinity. The sphere is placed along the vertical axis of the electromagnet. The measured position is determined from an array of infrared transmitters and detectors, positioned such that the infrared beam is intersected by the sphere [14].

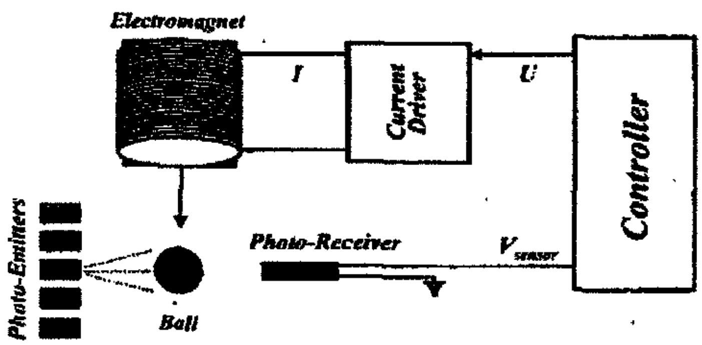


Figure 3: Main components of Magnetic Levitation System

2.2 Proportional Integral Derivative (PID)

The conventional controller such as PID controller is very reliable and simple controller to design. This controller used the method based on a linearization of the systems dynamics and compensates the effects of the non-modeled nonlinearity. Using this approach certain systems can be stabilized close to their nominal operating point. PID controller can be a robust and reliable system if the PID parameter can be determined or tuned that makes the system very stable [16].

As control system is needed, PID controller was developed many decades ago and being used as industrial controller until today. Proportional-Integral-Derivative Controller or known as PID Controller is the most common form of feedback and became the standard tool when process control was developed in 1940s. PID controllers have been utilized for control of diverse dynamical systems ranged from industrial process to aircraft and ship dynamics [17].

Although PID controller is the most popular controller for the majority of control systems, the classic tuning methods involved in the controller suffers with a few systematic design problems [18]. It is difficult to adjust the PID parameters and once the parameters are adjusted, they remain unchanged during the control systems operation [17].

Linear fixed-gain PID controllers are often acceptable for controlling a minor physical process; however the requirements for high-performance control with changes in operating conditions or environmental parameters are usually beyond the capabilities of simple PID controllers [17]. Nevertheless the most difficult part of PID controllers is how to alter the three parameters with the change of operating conditions and environmental parameters. It takes longer time to tune and get the best tuning of PID parameters.

PID controller is consists of the tuning parameter, Kp, Ti and Td. These parameters have their own function. For Kp, the change of output is proportional with the current value of error. For Ti, it accelerates the movement of the process towards setpoint and eliminates the residual steady-state error that occurs with a pure proportional controller. For Td, it is been multiply with the change of error over time. This parameter is used to speed up the slow performance process.

2.3 Fuzzy Logic Controller

The other control method that is popular among the engineers and scientists is Fuzzy Logic. The fuzzy set theory was introduced by Lofti Zadeh has become as a powerful modeling tool that can work with the unstable system and highly nonlinearities of modern control. It was intelligent control and the good thing about fuzzy logic control, the parameter of fuzzy logic is very easy to tune by non expert person if compare with PID controller that need experience person to tune the parameter [16], [21]. Fuzzy logic consists of main blocks which are Fuzzification, Inference Engine and Defuzzification as shown in Figure 4.

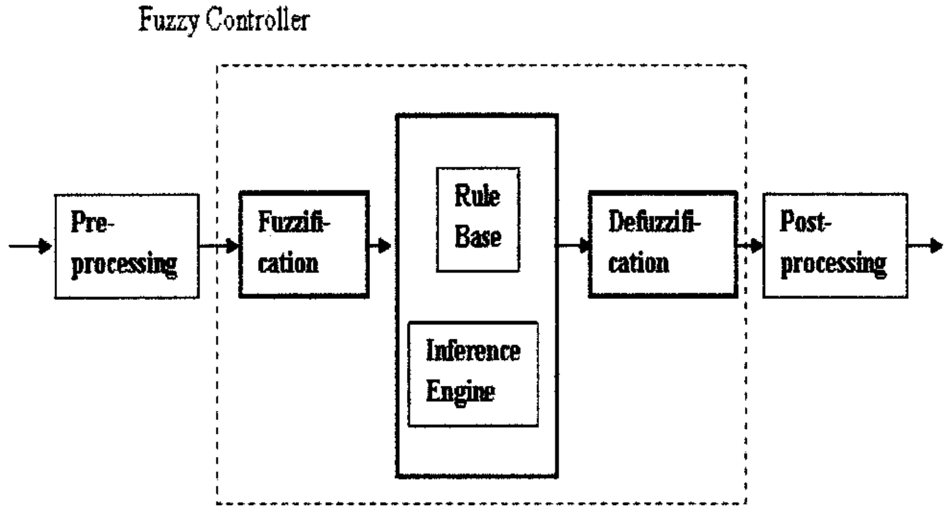


Figure 4: Block diagram of Fuzzy Logic controller

Fuzzification is used to convert each piece of input data to degrees of membership by a lookup in one or several membership functions. Inference Engine is the process of formulating the mapping from a given input to an output using fuzzy logic. The mapping then provides a basis from which decisions can be made, or patterns discerned. The process of fuzzy inference involves all of the pieces such as Membership Functions as shown in Figure 5, Rule Base as show in Figure 6, Logical Operations and If-Then Rules. There are two types of fuzzy inference systems that have been used widely such as Mamdani-type and Sugeno-type. These two types of inference systems vary somewhat in the way outputs are determined. Defuzzification is the inverse process of fuzzification which the decision taken on the input is transformed into a crisp output. The resulting fuzzy set must be converted to a number that can be sent to the process as a control signal.

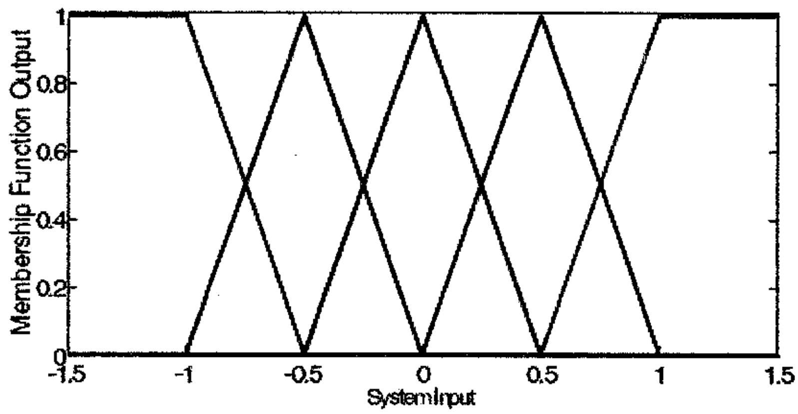


Figure 5: Example of Membership Function

"control voltage" V		"rate of change of error" $\dot{e}$				
		NB	NS	ZO	PS	PB
"error" e	NB	NB	NB	NB	NS	ZO
	NS	NB	NB	NS	ZO	PS
	ZO	NB	NS	ZO	PS	PM
	PS	NS	ZO	PS	PB	PB
	PB	ZO	PS	PB	PB	PB

Figure 6: Example of Rule Base

2.4 Fuzzy-PID controller

Fuzzy-PID controller mainly consists of two parts, conventional PID controller and Fuzzy Logic controller, as shown in Figure 7. The Fuzzy-PID controller is based on the conventional PID control algorithm, through computing the system's current error e and error change rate e_c, inquires fuzzy matrix table by using Fuzzy Inference System (FIS) and carries on the on-line adjustment to the three PID parameters: $\Delta K_p, \Delta K_i, \Delta K_d$.[20]

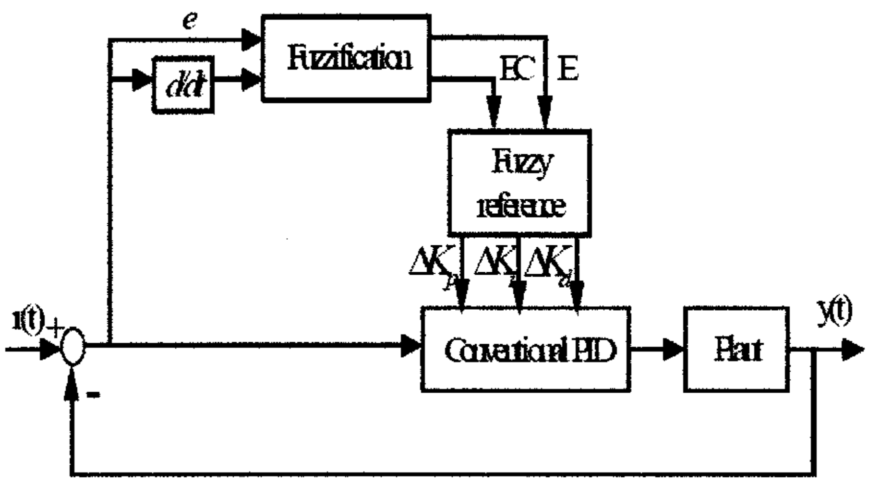


Figure 7: Fuzzy-PID control system

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

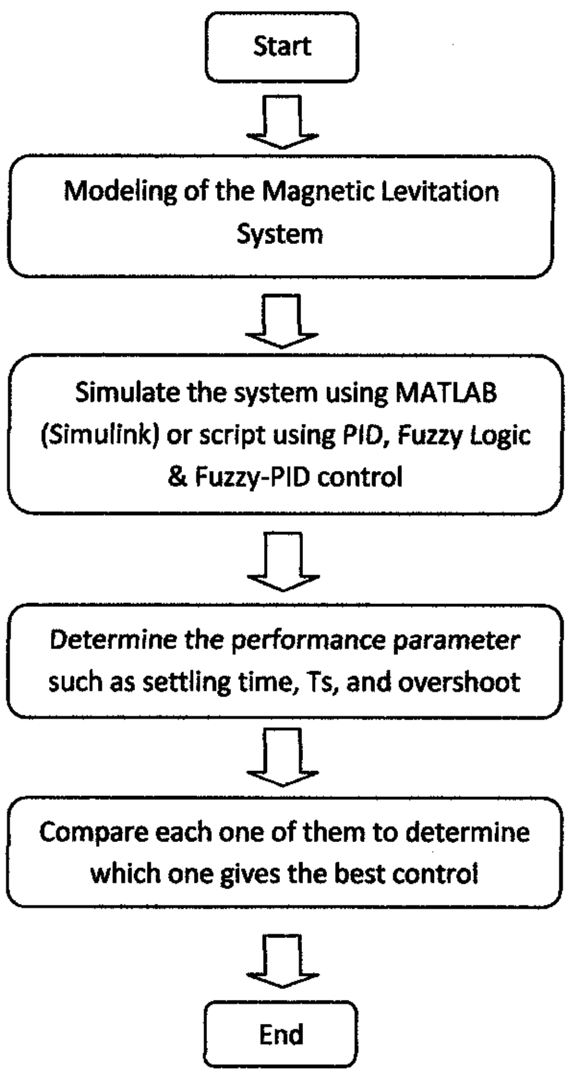


Figure 8: Process flow of the project

3.2 Project Activities

Based on the Figure 8 earlier, here are the detailed descriptions of the project activities to be completed along the two semesters:

Table 1: Project Activities:

Research Methodology	Description
Modeling of the Magnetic Levitation System	Deriving the mathematical equation and converts it into transfer function. Transfer function is a form of mathematical equation that can be used in MATLAB for simulation purpose
Simulate the system using MATLAB (Simulink) or script using PID, Fuzzy Logic and Fuzzy-PID control	Using Simulink or script in MATLAB, the differential equation is transform in the form of block diagram. Different control method such PID control is introduced to the system. Then Fuzzy logic control is implemented and combined with the PID control to get Fuzzy-PID control. These three control methods are simulated using MATLAB
Determine the performance parameter such as settling time, Ts, and overshoot	From the output response, the performance parameters can be determined which will be used to compare each one of them with the others.
Compare each one of them to determine which one gives the best control	These performance parameters such as settling time and overshoot will determine either the system is a good or bad system. For example, lowest settling time among the three control methods determine the system is a good system.

3.3 Tools and Equipment

The tools required to complete this project is using software only. The software used is MATLAB which is very popular and suitable software for the control system and technical computing. To design the system in MATLAB, Simulink blocks have been used. There, all the blocks will be connected to represent the system. It also has the Fuzzy Logic toolbox which will be used to develop the Fuzzy Logic control for the magnetic levitation system. The project also is in the range of time allocated by the coordinator.

3.4 Modeling of Magnetic Levitation System

The Magnetic Ball Plant model represents an iron ball of mass *M*. This ball moves under the influence of the gravitational force, *Mg*, and an induced magnetic force, $\frac{Bi^2}{h}$. The presence of the squared term in the induced magnetic force results in a nonlinear plant. The inductor in the electric circuit, shown in the following figure, causes the induced magnetic force. This circuit also includes a voltage source and a resistor. Figure 9 shows the magnetic levitation system model.

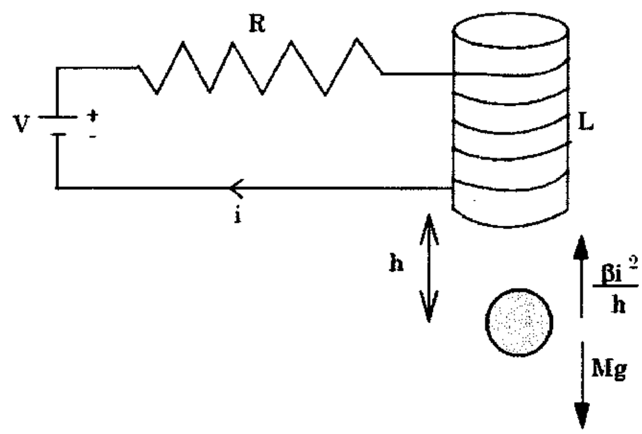


Figure 9: Magnetic Levitation System model

A differential equation for the force balance on the ball is given by

$$\frac{Md^2h}{dt^2} = Mg - \frac{Bi^2}{h}$$

where *M* is the mass of the ball, *h* is the height (position) of the ball, *g* is the acceleration due to gravity, *i* is the current, and β is a constant related to the magnetic force experienced by the ball. This equation describes the height, *h*, of the ball due to the unbalanced forces acting upon it.

The current in the circuit also varies with time and is given by the following differential equation

$$L\frac{di}{dt} = V - iR$$

where L is the inductance of the coil, V is the voltage in the circuit, and R is the resistance of the circuit.

The system of equations has three states:

$$h, \frac{dh}{dt}, i$$

The system also has one input (V), and one output (h). It is a nonlinear system due to the term in the equation involving the square of i and the inverse of h.

Due to its nonlinearity, you cannot analyze this system using methods for linear-time-invariant (LTI) systems such as step response plots, bode diagrams, and root-locus plots. However, you can linearize the model with Simulink Control Design to approximate the nonlinear system as an LTI system. Linearization also occurs automatically when designing a compensator with Simulink Control Design. This linearized system can then use the LTI Viewer for display and analysis and the SISO Design Tool for compensator design.

The input to the Magnetic Ball Plant system, which is also the output of the Controller subsystem, is the voltage, V. The output is the height of the ball, h. The system contains three states within the three integrators: height, $\frac{dh}{dt}$, and current.

Table 2: MagLev System Parameters

M	Mass of the ball	0.1 kg
g	Gravitational acceleration	9.81 m/s^2
R	Resistance of the circuit	2Ω
L	Inductance of the coil	0.02H
β	Constant related to the magnetic force	0.001

3.5 Simulation of Magnetic Levitation System

3.5.1 PID Controller

Figure 10 shows the PID controller simulink model of the Magnetic Levitation system. The desired height of the ball is approximately 0.05m. The value of Kp, Ki and Kd that being used in the simulation are shown in Table 3. These values are based from heuristic evaluation. The parameters cannot be determined by Ziegler-Nichols or Cohen-coon tuning method since there is no way to get the oscillation if Kp is set to 1, Ki is set to 999999 and Kd is set to 0.

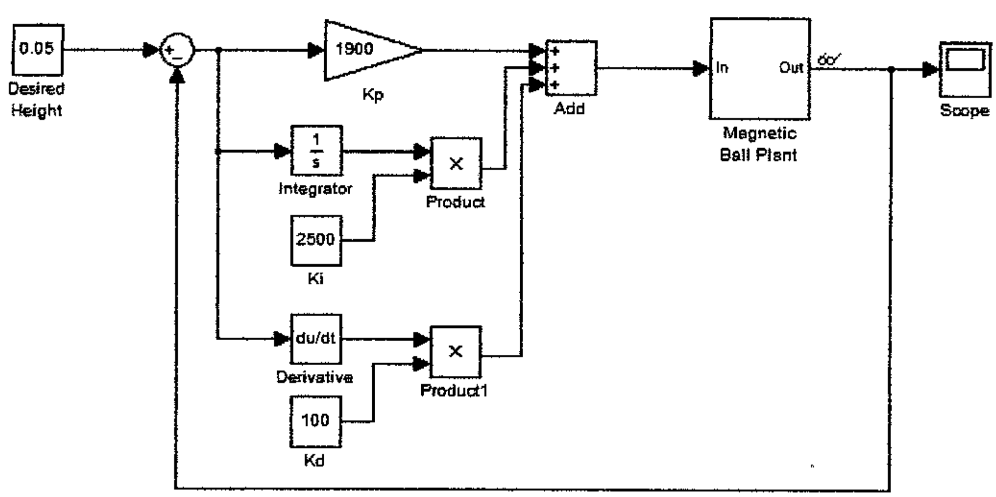


Figure 10: PID controller for the Magnetic Levitation system

Table 3: PID controller tuning parameters

No	Tuning Parameters Value
1	Kp= 1700 Ki= 2500 Kd= 100
2	Kp= 1900 Ki= 2500 Kd= 100
3	Kp= 1900 Ki= 1000 Kd= 100
4	Kp= 1900 Ki= 2500 Kd= 75
5	Kp= 1900 Ki= 2500 Kd= 50

Figure 11 shows the simulink diagram for the magnetic ball plant subsystem. These blocks are derived from the linearization using Simulink Control Design.

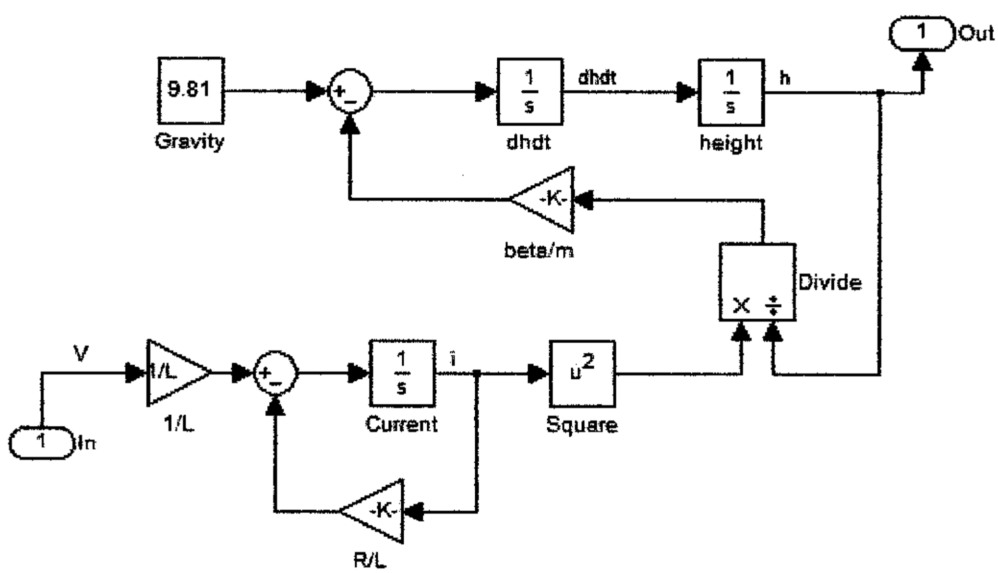


Figure 11: Magnetic Ball plant subsystem

3.5.2 Fuzzy Logic Controller

Figure 12 shows the simulink model of the fuzzy logic controller of the system. The inputs that enter the fuzzy logic block are error, e and change of error, Δe. The output that goes off the block is output, u. Each of the input and output has their own gain.

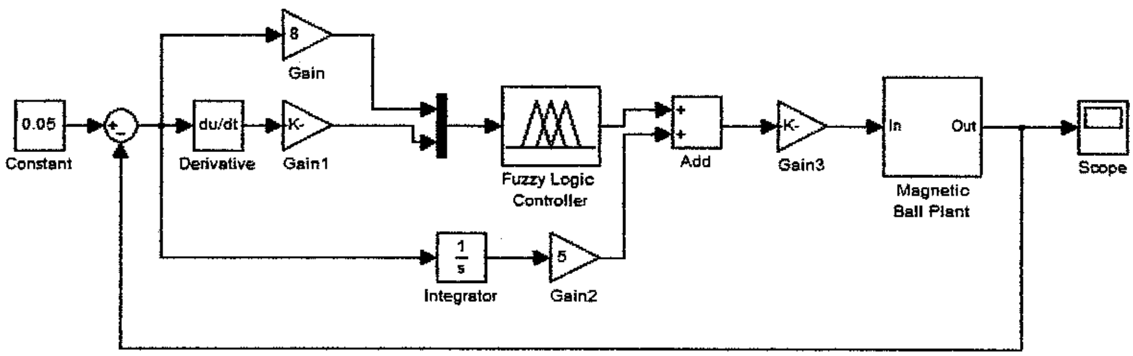


Figure 12: Fuzzy Logic controller for Magnetic Levitation system

3.5.2.1 3x3 Membership Function

For 3x3 membership function, there are three elements in input which are Negative Small (NS), Zero (Z) and Positive Small (PS). The range of the membership function for e, Δe and u are [-10 10], [-1 1] and [-5 5] respectively. Table 4 shows the control rule base for 3x3 membership function. The gain for e and Δe are 8 and 0.05 respectively. The gain for output, u is shown in Table 5.

Table 4: 3x3 control rule base

e/Δe	N	Z	P
N	N	N	Z
Z	N	Z	P
P	Z	P	P

Table 5: Fuzzy (3x3) output gain value

No	Output gain, u value
1	u =350
2	u =450
3	u =550

Figure 13, 14 and 15 show the membership function for *e*, Δ*e* and u respectively.

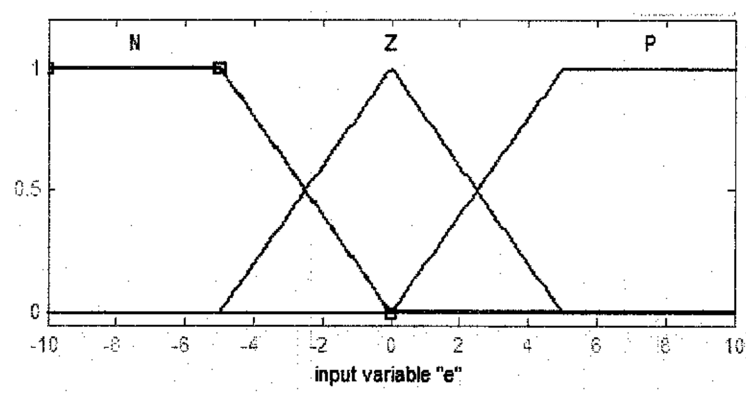


Figure 13: Membership function for error (3x3)

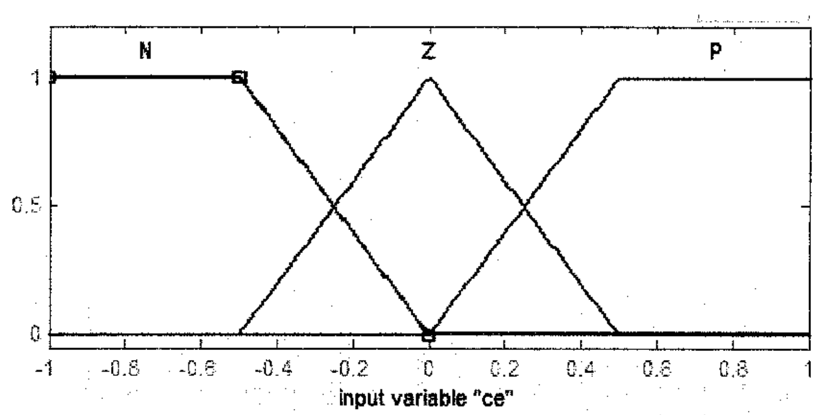


Figure 14: Membership function for change of error (3x3)

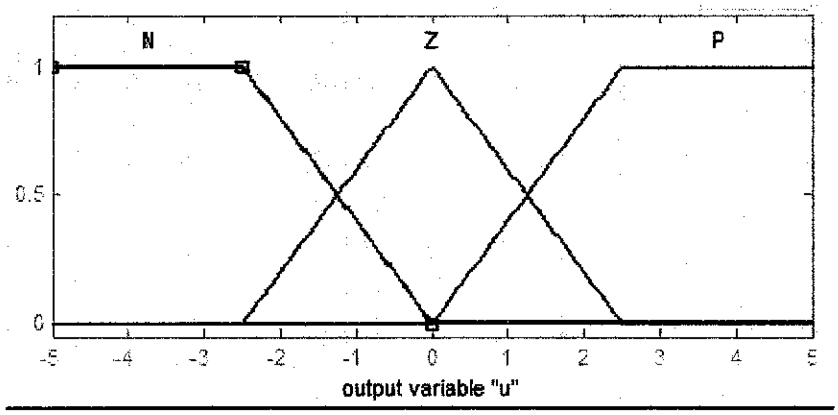


Figure 15: Membership function for output (3x3)

3.5.2.2 5x5 Membership Function

For 5x5 membership function, there are three elements in input which are Negative Big (NB), Negative Small (NS), Zero (Z), Positive Small (PS) and Positive Big (PB). The range of the membership function for *e*, Δe and u are [-10 10], [-1 1] and [-5 5] respectively. Table 6 shows the control rule base for 5x5 membership function. The gain for *e* and Δe are 8 and 0.05 respectively. The gain for output, u is shown in Table 7.

Table 6: 5x5 control rule base

e/Δe	NB	NS	Z	PS	PB
NB	NB	NB	NB	NS	Z
NS	NB	NB	NS	Z	PS
Z	NB	NS	Z	PS	PB
PS	NS	Z	PS	PB	PB
PB	Z	PS	PB	PB	PB

Table 7: Fuzzy (5x5) output gain value

No	Output gain, u value
1	u =350
2	u =450
3	u =550

Figure 16, 17 and 18 show the membership function for *e*, Δ*e* and u respectively.

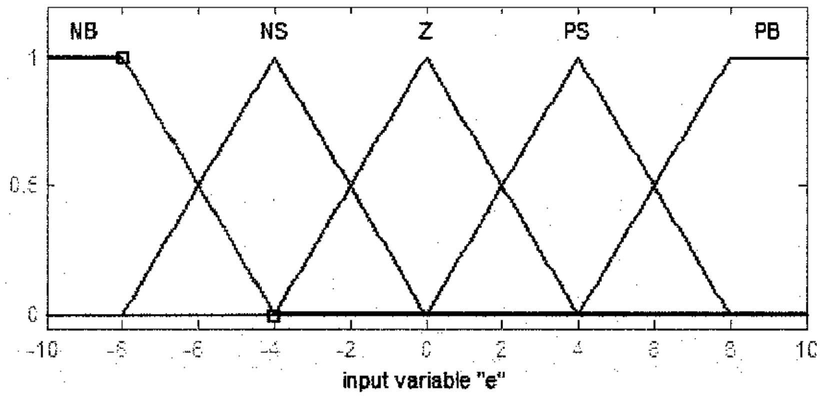


Figure 16: Membership function for error (5x5)

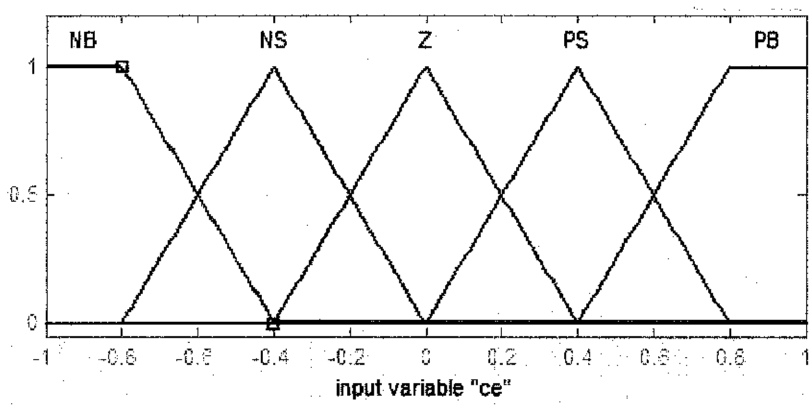


Figure 17: Membership function for change of error (5x5)

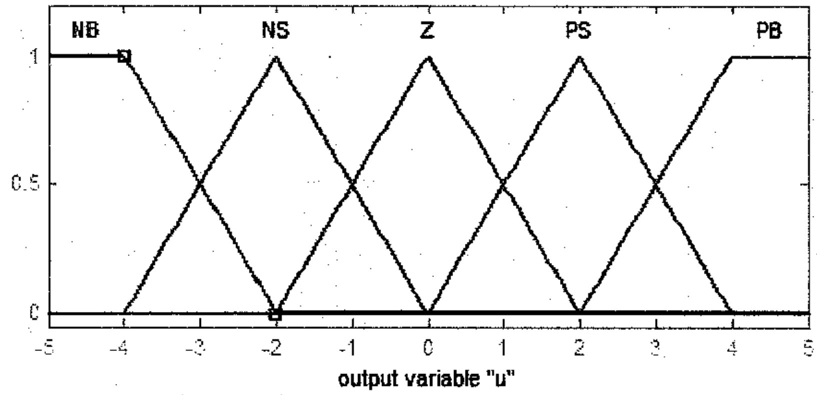


Figure 18: Membership function for output (5x5)

3.5.2.3 7x7 Membership Function

For 7x7 membership function, there are three elements in input which are Negative Big (NB), Negative Middle (NM), Negative Small (NS), Zero (Z), Positive Small (PS), Positive Middle (PM) and Positive Big (PB). The range of the membership function for *e*, Δ*e* and u are [-10 10], [-1 1] and [-5 5] respectively. Table 8 shows the control rule base for 7x7 membership function. The gain for *e* and Δ*e* are 8 and 0.05 respectively. The gain for output, u is shown in Table 9.

Table 8: 7x7 control rule base

e/Δe	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NB	NS	Z
NM	NB	NM	NM	NM	NS	Z	PS
NS	NB	NM	NM	NS	Z	PS	PB
Z	NB	NM	NS	Z	PS	PM	PB
PS	NB	NS	Z	PS	PM	PM	PB
PM	NS	Z	PS	PM	PM	PM	PB
PB	Z	PS	PB	PB	PB	PB	PB

Table 9: Fuzzy (7x7) output gain value

No	Output gain, u value
1	u =450
2	u =550
3	u =650

Figure 19, 20 and 21 show the membership function for *e*, Δ*e* and u respectively.

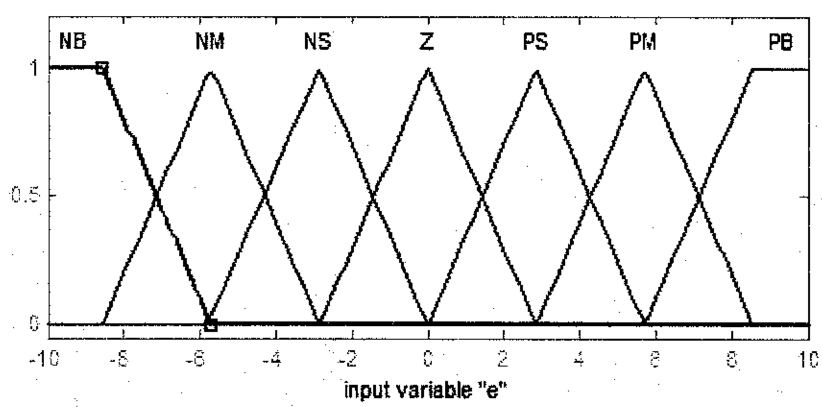


Figure 19: Membership function for error (7x7)

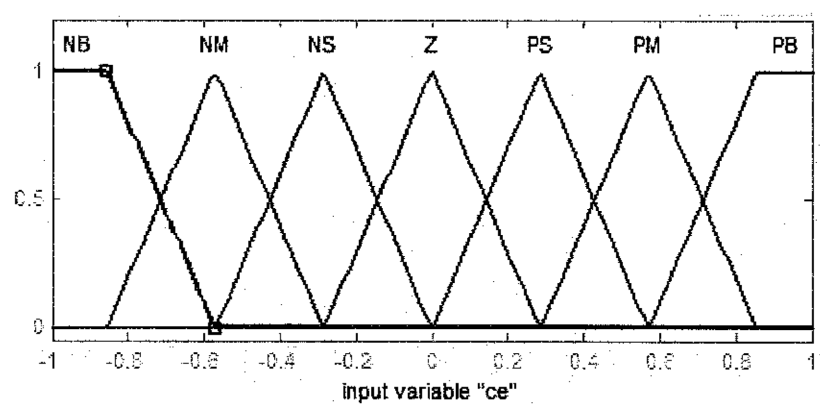


Figure 20: Membership function for change of error (7x7)

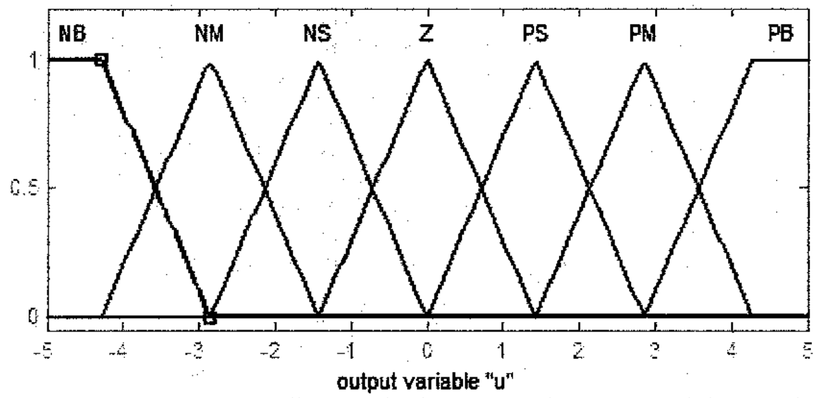


Figure 21: Membership function for output (7x7)

3.5.3 Fuzzy-PID controller

Figure 22 shows the simulink model of the Fuzzy-PID controller of the system. The gain for e, Δe and u are 8, 0.05 and 1.5 respectively. The inputs that enter the fuzzy logic block are error, e and change of error, Δe. The outputs that go off the block are ΔKp, ΔKi and ΔKd. Table 10, 11 and 12 show the control rule base for ΔKp, ΔKi and ΔKd respectively. The output gain, u value is 1.5 only.

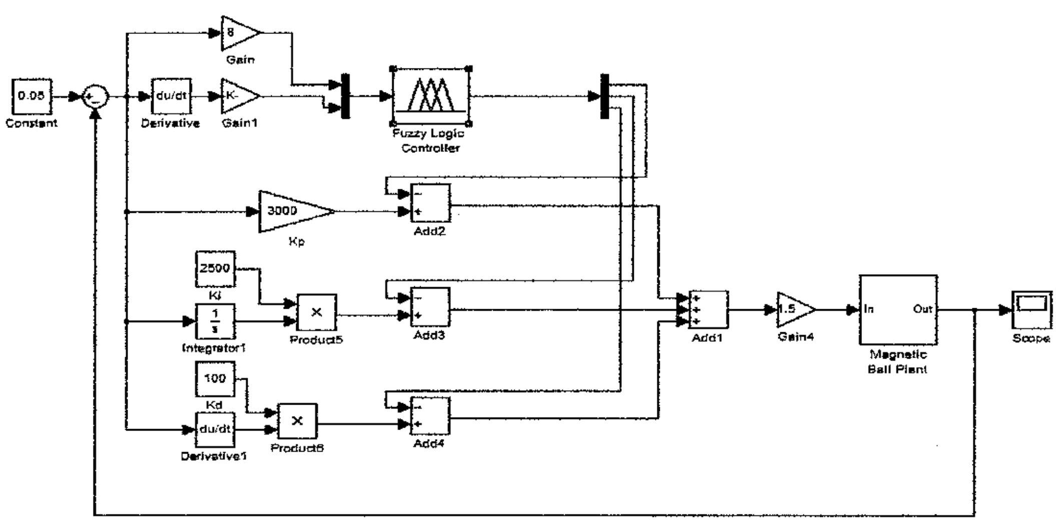


Figure 22: Fuzzy-PID controller for Magnetic Levitation system

Table 10: 7x7 control rules base for ΔKp

e/Δe	NB	NM	NS	Z	PS	PM	PB
NB	PB	PB	PM	PM	PS	PS	Z
NM	PB	PB	PM	PS	PS	Z	Z
NS	PM	PB	PM	Z	Z	NS	NM
Z	PM	PM	PS	Z	PS	NM	NM
PS	PS	PS	Z	Z	NS	NM	NM
PM	Z	Z	NS	NS	NM	NM	NM
PB	Z	NS	NS	NM	NM	NB	NB

Table 11: 7x7 control rules base for ΔKi

e/Δe	NB	NM	NS	Z	PS	PM	PB
NB	Z	Z	Z	PS	PS	PM	PM
NM	Z	Z	PS	PS	PS	PM	PM
NS	PS	Z	PS	PS	PM	PM	PM
Z	PS	PS	PS	PM	PM	PM	PB
PS	PS	PS	PM	PM	PM	PB	PB
PM	PM	PM	PM	PB	PB	PB	PB
PB	PM	PM	PM	PB	PB	PB	PB

Table 12: 7x7 control rules base for ΔKd

e/Δe	NB	NM	NS	Z	PS	PM	PB
NB	PM	PM	PM	PM	PM	PB	PB
NM	PS	PS	PS	PS	PM	PS	PB
NS	Z	Z	PS	PS	PM	PS	PB
Z	Z	PS	PS	PS	PM	PM	PB
PS	Z	PS	PS	PS	PM	PM	PM
PM	PS	PS	PS	PS	PM	PM	PM
PB	PM	PM	PM	PM	PM	PB	PB

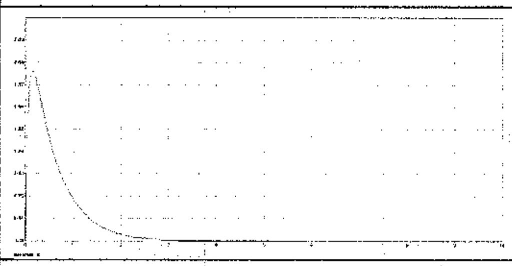
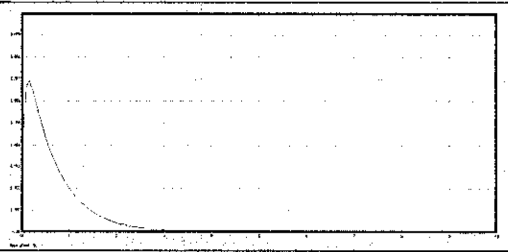
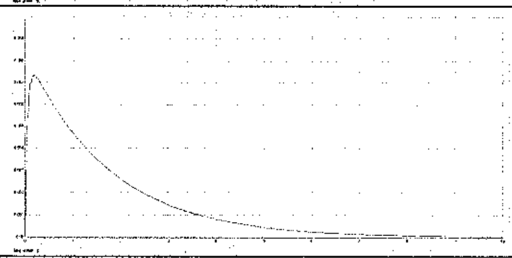
CHAPTER 4

RESULTS & DISCUSSION

4.1 Results of the simulation

Using Simulink, all the models such as PID, Fuzzy (3x3), Fuzzy (5x5), Fuzzy (7x7) and Fuzzy-PID controller were simulated and the results are shown in the Table 13, Table 14, Table 15, Table 16 and Table 17 respectively.

Table 13: Result for PID controller

Tuning Parameters Value	Output response	Performance parameters
Kp= 1700 Ki= 2500 Kd= 100		Overshoot = 0.0573 Settling Time = 4 s
Kp= 1900 Ki= 2500 Kd= 100		Overshoot = 0.0570 Settling Time = 3 s
Kp= 1900 Ki= 1000 Kd= 100		Overshoot = 0.0573 Settling Time = 8 s

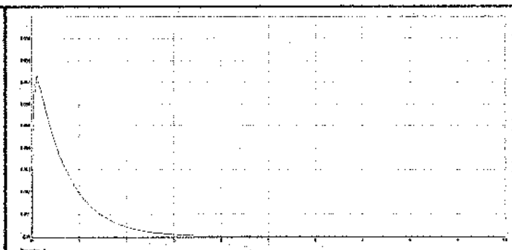
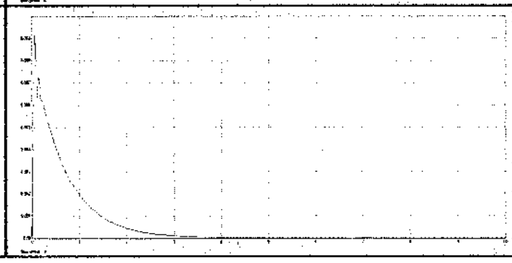
Kp= 1900 Ki= 2500 Kd= 75		Overshoot = 0.0572 Settling Time = 4 s
Kp= 1900 Ki= 2500 Kd= 50		Overshoot = 0.0591 Settling Time = 4 s

Table 14: Results for Fuzzy Logic (3x3)

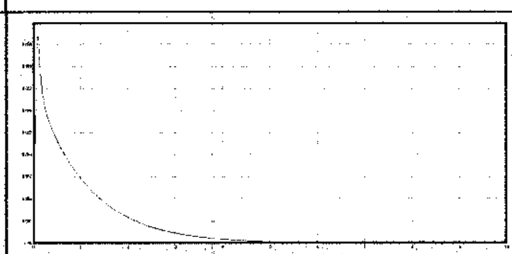
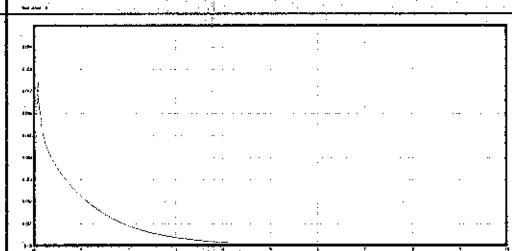
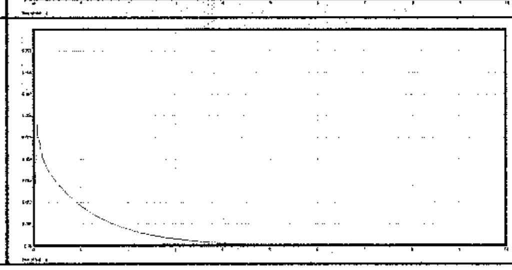
Output Gain Value	Output response	Performance parameters
u= 350		Overshoot = 0.0594 Settling Time = 5 s
u= 450		Overshoot = 0.0575 Settling Time = 5 s
u= 550		Overshoot = 0.0556 Settling Time = 4.5 s

Table 15: Results for Fuzzy Logic (5x5)

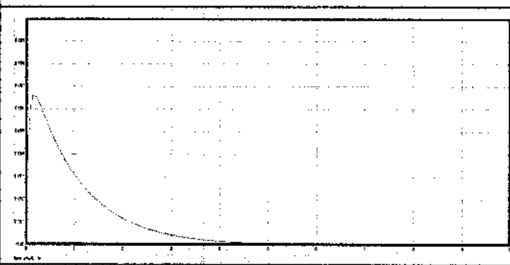
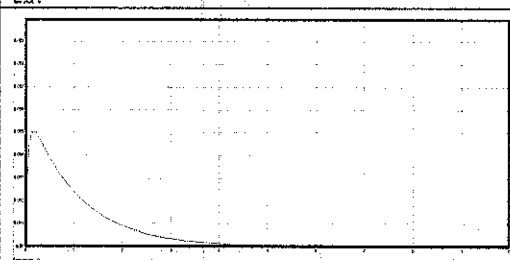
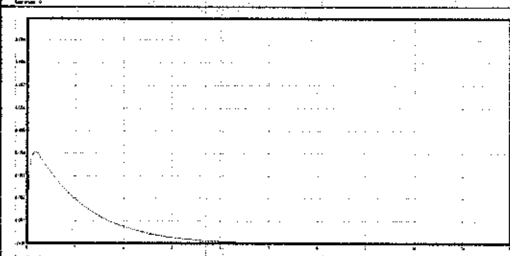
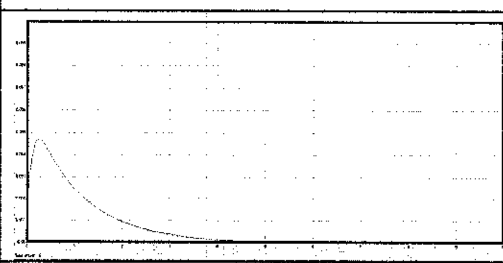
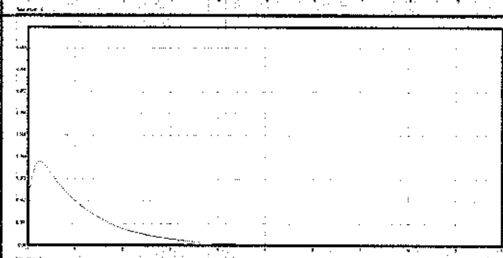
Output Gain Value	Output response	Performance parameters
u= 350		Overshoot = 0.0566 Settling Time = 4.5 s
u= 450		Overshoot = 0.0550 Settling Time = 4.5 s
u= 550		Overshoot = 0.0541 Settling Time = 4.5 s

Table 16: Results for Fuzzy Logic (7x7)

Output Gain Value	Output response	Performance parameters
u= 450		Overshoot = 0.0547 Settling Time = 4.5 s
u= 550		Overshoot = 0.0538 Settling Time = 4.5 s

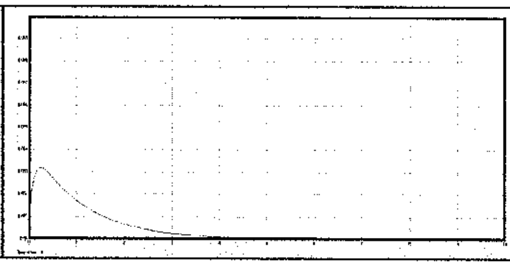
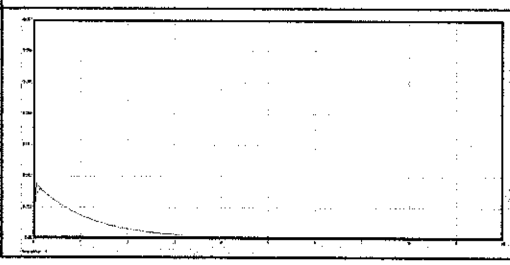
u= 650		Overshoot = 0.0533 Settling Time = 4.5 s

Table 17: Results for Fuzzy-PID (7x7)

Output Gain Value	Output response	Performance parameters
u= 1.5		Overshoot = 0.0518 Settling Time = 4.5 s

From the simulation results, the best output response from each table is shown in Table 18.

Table 18: Summarization of the best output response from each table of results

Control Method	Parameters / Gain	Performance Parameter
PID	Kp= 1900 Ki= 2500 Kd= 100	Overshoot = 0.0570 Settling Time = 3 s
Fuzzy Logic (3x3)	u= 550	Overshoot = 0.0556 Settling Time = 4.5 s
Fuzzy Logic (5x5)	u= 550	Overshoot = 0.0541 Settling Time = 4.5 s
Fuzzy Logic (7x7)	u= 650	Overshoot = 0.0533 Settling Time = 4.5 s
Fuzzy-PID (7x7)	u= 1.5	Overshoot = 0.0518 Settling Time = 4.5 s

The type of error in this simulation is systematic error. Systematic error is error which tends to shift all measurements in a systematic way so their mean value is displaced. In a sense, a systematic error is rather like a blunder and large systematic errors can be eliminated. But small systematic errors will always be present. For instance, the height of the ball cannot be perfectly stayed at 0.05 m from the electromagnetic coil. This is due to the difficulties because the ball does not stay in one place but moves either towards the earth due to gravitational force or towards the coil due to magnetic force.

The error measurement used in this project is percentage error. Percentage error is used when we are comparing our estimated value to an actual value. First, subtract the two values so that the difference we get is a positive number. This is called taking the absolute value of the difference. Then we divide this result (the difference) by the actual value to get a fraction, and then multiply by 100% to get the percent error. The formula is shown below:

$$\text{Percentage error} = \frac{|\text{estimated value} - \text{actual value}|}{\text{actual value}} \times 100\%$$

The summary of the results with the percentage error for each controller is summarized in Table 10.

Table 19: Summarization of percentage error of overshoot value for each controller

Control method	Overshoot value	Percentage error (%)
PID	0.0570	14
Fuzzy Logic (3x3)	0.0556	11.2
Fuzzy Logic (5x5)	0.0541	8.2
Fuzzy Logic (7x7)	0.0533	6.6
Fuzzy-PID (7x7)	0.0518	3.6

4.2 Discussion of the results

Magnetic Levitation System is a non-linear and unstable system since it is affected by the gravity. To control the height of the levitated at a fixed position, just only closed-loop system is not enough to stabilize the system. It requires better controller to compensate the non-linear system. In this project, the PID, Fuzzy Logic and Fuzzy-PID controller were chosen to be implemented to the Maglev system.

The output of the magnetic levitation system is observed and analyzed. Apart from that, comparisons are made to see which controller gives better performance by considering the settling time and overshoot value.

From the results, we can conclude that the PID controller gain is proportional with time integral. This means when the Kp value is bigger, the output will have smaller value of offset but the more oscillatory the process becomes. Where else, if the Ti is bigger, the offset is bigger but the oscillation is less. The value of Kp, Ki and Kd that being used are 3000, 2500 and 100 respectively. These values are based from heuristic evaluation. The parameters cannot be determined by Ziegler-Nichols tuning method since there is no way to get the oscillation if Kp is set to 1, Ki is set to 999999 and Kd is set to 0.

As for the Fuzzy Logic controller, the response is slower than PID controller. However, Fuzzy Logic controller shows the better performance than PID controller in terms of lowest overshoot and settling time. From the results also we can see that larger set of rules yield more accurate control to the system. For example, 7x7 control rules is better than 5x5 control rules, followed by 3x3 control rules. Scaling factors are most important with respect to fuzzy controller performance and provide a guideline for tuning. For this project, the output gain value, u was varied to get the best output response. In the fuzzy controller, if there not provide the integration of error, the steady state error cannot be eliminates. That is why here integration of error need to apply in the membership function.

As for Fuzzy-PID controller, it is a combination of Fuzzy Logic and conventional PID controller. The Fuzzy Logic controller has two inputs (error and change of error) and three outputs (ΔKp, ΔKi and ΔKd). The PID controller has one input for each Kp, Ki and Kd blocks which yield the control parameters for the complete

Fuzzy-PID controller. The Fuzzy Logic controller is consists of three different control rule bases that will carry the online adjustment to the three PID parameters, for each of ΔKp, ΔKi and ΔKd. This combination between Fuzzy and PID controller provide the best control technique compared to PID and Fuzzy Logic in terms of overshoot value and percentage error as shown in Table 10.

To the non-linear features of the maglev system, a fuzzy PID controller through the combination of traditional PID control and fuzzy control technology is designed using the MATLAB software. Simulation results show that the response of ball position has less response time and less overshoot. However, because of the complex algorithms of fuzzy control, we have to do much more calculation. All of the above are in the higher need of the processing speed of the hardware and real-time operation.

CHAPTER 5

CONCLUSION & RECOMMENDATION

As a conclusion, this project is complete successfully and achieved the outcome that has been set by the supervisor. The implementation of PID, Fuzzy Logic and Fuzzy-PID controller have been successfully simulated using MATLAB and all the performance parameters such as settling time and overshoot value have been recorded.

Based on the results of the simulation, Fuzzy-PID controller is the best controller followed by Fuzzy Logic (7x7 rule base), Fuzzy Logic (5x5 rule base), Fuzzy Logic (3x3 rule base) and PID controller. For Fuzzy Logic controller, larger the set of rules yield more accurate and precise control to the system. The combination of Fuzzy Logic (7x7 rule base) and conventional PID controller are been implemented, produce the Fuzzy-PID controller which is the best controller among them. Overall, no difficult problem encountered. This project is expected to be completed after the full integration is been done.

For further development about this project, the extensions of this research lie primarily in the areas of implementation and applications of the Fuzzy Logic controller. It is highly recommended that a faster Digital Signal Processing (DSP) be used for the implementation of the Fuzzy Logic. In the future, it can be implemented the Neural Network controller to control the Maglev system. Then, there should be integration between the computer and the Magnetic Levitation kit. So the control can be implemented in real-time and can be the tools for laboratory and teaching purposes. Hence, the project can help the students to appreciate and understands the benefit of Magnetic Levitation system. So no wonder this project can provide many benefits to the engineering students and should be taken into consideration by the Board of Electrical and Electronics Engineering to implement this project as the laboratory purposes for Control System subjects.

CHAPTER 6

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APPENDIX A
GANTT CHART

Final Year Project I Gantt Chart

Final Year Project II Gantt Chart