PERFORMANCE ANALYSIS OF MAGNETIC LEVITATION SYSTEM USING DIFFERENT CONTROL ALGORITHMS

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SUBMITTED BY:

Vasudha Sharma
2K21/C&I/09

UNDER THE SUPERVISION OF

PROF. NARENDRA KUMAR (II)

PROF. RAM BHAGAT

DEPARTMENT OF ELECTRICAL ENGINEERING
DELHI TECHNOLOGICAL UNIVERSITY
(Formerly Delhi College of Engineering) Bawana Road, Delhi-110042

MAY 2023

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering) Bawana Road, Delhi-110042

CANDIDATE'S DECLARATION

I, Vasudha Sharma, Roll No – 2k21/C&I/09 student of M.Tech (Control & Instrumentation), hereby declare that the project Dissertation titled "**PERFORMANCE ANALYSIS OF MAGNETIC LEVITATION SYSTEM USING DIFFERENT CONTROL ALGORITHMS**" which is submitted by me to the Department of Electrical Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

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Date: **(Vasudha Sharma)**

ELECTRICAL ENGINEERING DEPARTMENT

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering) Bawana Road, Delhi-110042

CERTIFICATE

I hereby certify that the Project Dissertation titled "**PERFORMANCE ANALYSIS OF MAGNETIC LEVITATION SYSTEM USING DIFFERENT CONTROL ALGORITHMS**" which is submitted by Vasudha Sharma, whose Roll No. is 2k21/C&I/09, Electrical Engineering Department, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the students under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Place: Delhi **PROF. NARENDRA KUMAR**

Date: (**SUPERVISOR)**

Place: Delhi **PROF. RAM BHAGAT**

Date: (**SUPERVISOR)**

ABSTRACT

This research work aims to control and stabilize the Magnetic Levitation system, which levitates a magnetic ball in space being under the influence of a magnetic field only. Magnetic Levitation is a keen area of research as it reduces cost of maintenance and increases its efficiency. It has numerous applications in industries. To name a few of the applications, transportation and low friction bearings are some.

Different controllers are used to stabilize the highly unstable nature of the maglev system. The transfer function is constructed through dynamic model analysis, which is then applied to a more straightforward mathematical model. Different controllers used are PD, PID and PID plus double derivative. Various time domain parameters like Settling time, Peak time, Rise time, and Maximum Overshoot are computed and compared with differently tuned PID gain values which are calculated after applying optimization algorithms. The applied algorithms for optimization are Genetic Algorithm, Particle Swarm Optimization, Giza Pyramids Construction and Honey Badger Algorithm. The applied algorithms are found to be helpful in reaching a steady state at a faster rate with less steady state error.

May, 2023 Vasudha Sharma

Delhi (India) (2K21/C&I/09)

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(2k21/C&I/09)

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ACRONYMS

PID	Proportional Integral Derivative
Maglev	Magnetic Levitation
PSO	Particle Swarm Optimization
GA	Genetic Algorithm
GPC	Giza Pyramids Construction
HBA	Honey Badger Algorithm
SSE	Steady State Error
SOM	Self Organizing maps

CHAPTER 1

MAGNETIC LEVITATION

1.1 INTRODUCTION

The concept of magnetic levitation is applied in Maglev system in which the object is suspended in the space without any external physical support except magnetic field. Maglev system is a single input single output with high instability and non-linearity in nature. The system is made to be linear and stable in order to be applied to real world applications [1].

1.2 OVERVIEW

Magnetic Levitation is the method in which the object is made to be suspended in the air space under the influence of the magnetic field only. Magnetic force is used to counter the effect of gravitational force acting on the object. There are two prominent issues which need to be resolved in maglev system. One is the issue of **lifting forces** i.e. providing an upward force sufficient to counter the effect of gravity and the other issue is **stability** i.e. ensuring the system doesn't flip or slide and remain stable throughout.

Maglev uses the electromagnetic force to suspend the object in air, which effectively reduces the friction induced by mechanical vibrations and the wearing losses which are caused by contact operations. The parameters are related to permanent geometry of magnet, mass of the object and the distance of its suspension.

Earnshaw's theorem states that if only paramagnetic materials are used, it is not possible for a system to stabilize statically against gravity [2]. **Static stability** is defined in the way that any little displacement which is away from the stable equilibrium can cause a force which pushes it back in the equilibrium. In addition, D**ynamic stability,** is defined in which the system is able to damp out any vibrations. Magnetic fields are forces which are conservative in nature and they have no in-built damping mechanism which can permit vibrations to exist eventually make them leave the stable region [3].

Damping can be done in the following ways:

a) External mechanical damping like dashpots and air drag.
b) Tuned mass dampers
c) Eddy currents damping

Eddy currents are observed in maglev system to stabilize the levitated object. Eddy currents produce magnetic field which in turn opposes the levitated object's motion as per Lenz's law.

1.3 BASICS OF MAGNETIC FIELD

The magnetic field can be found out at any point using the equation given by Biot Savart's law.

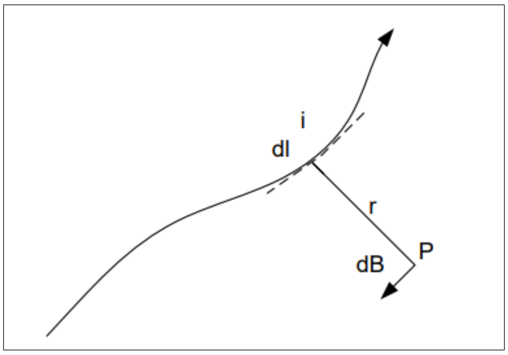

Figure 1.1 Current carrying wire exerts magnetic field at P

The above said law states that an element *'dl'* which is carrying current *'i'* contributes to a magnetic field *'B'* at any point '*p*' which lies perpendicular to plane of *'dl'* with vector *'r'* that is given by

$$dB = \frac{\mu_o i\, dl\, \sin\theta}{4\pi r^2} \quad (1.1)$$

Where, μ_o is permeability constant of the free space

i is current in element

B is magnetic field

dl is the small section of the wire that carries current

r is vector from the element to the point 'P'

Electromagnetic coil is used in producing the magnetic field. Maglev is a concept involving electromagnetic coupling [4]. The magnetic field is generated by the coil wherein electrical part attracts the magnetizable object. When the object starts moving away from the magnet, the current of the coil decreases and vice versa. Magnetic levitation can either be by attraction or repulsion.

1.4 APPLICATIONS

Maglev provides friction less movement and isolation with environment. A few of the applications for the same are stated below:

a) Magnetic Levitation Train

The train needs to move along the guide way under the influence of magnetic field that helps the train in propelling and levitating. The first commercial implementation of maglev train was Shanghai’s Trans rapid system which used German model

b) Magnetic bearings

These use rotor for the levitation and rotation with magnetic flux interaction by stator mounted electromagnet. Due to absence of friction, drag or wear and tear of parts, these are used in flywheel as energy storage devices.

c) Launching Rocket

It involves developing a track which levitates the rocket and give it a required initial velocity to escape velocity of Earth. This project intends to make transportation less costly.

d) Maglev wind turbine

Magnetically levitated wind turbine can be 20% more efficient as compared to traditional wind turbines. Since efficiency is more so, area, which is required to generate the same power, is much lesser than the traditional turbine.

1.5 SCOPE OF WORK

Significant contributions of this study are:

- Use of new controller PID plus double derivative controller in the feedback

- Proposing use of the Giza Pyramids Construction Algorithm (GPC) and Honey Badger Algorithm(HBA) for determining the optimal gain values for the PID controller.
- A Step, sine and square wave signal have used as the reference signals to test the efficacy of the proposed methods.
- To assess the performance of Giza Pyramids Construction Algorithm (GPC) and Honey Badger Algorithm (HBA) compared to PSO and GA for finding optimal gain values of the controllers for the Magnetic Levitation System.

1.6 THESIS ORGANIZATION

The content of the thesis is organized in eight chapters:

- Chapter I INTRODUCTION
- Chapter II MODELLING OF MAGLEV SYSTEM
- Chapter III DESIGINING OF CONTROLLERS FOR MAGLEV
- Chapter IV OPTIMIZING ALGORITHMS
- Chapter V SIMULATION AND RESULTS
- Chapter VI CONCLUSION AND FUTURE SCOPE

Chapter I – Includes the introduction about maglev system and overview about magnetic levitation system. Basics of magnetic field has been discussed along with its applications. A detailed literature review has been written which records the types of researches done yet on maglev system.

Chapter II – This chapter is literature review, which gives an insight about the research papers published till date on magnetic levitation.

Chapter III – This chapter gives an insight about the hardware system of the maglev and its mathematical modelling along with its block diagram.

Chapter IV – This chapter includes the various types of controllers used in feedback to stabilize the maglev system

Chapter V – This chapter includes the various types of optimizing methods to be used in finding the gain values of the controllers. It discusses methods like PSO, GA, GPC and HBA. The last two are newly developed algorithms in 2021.

Chapter VI – This chapter includes the simulations and results. The results include the responses obtained by PD, PID and PIDD2 controller.

Chapter VII – This includes the conclusion about the research work and future scope further.

CHAPTER 2

LITERATURE REVIEW

Classical PID controllers have been used in tracking and controlling the position of the metallic ball at a certain height. The proportional part of the controllers helps in improving the transient response at a faster pace, the integral part improves the steady-state response and reduces steady-state error while the derivative part improves the transient response and reduces ripples and overshoots. Hit, trial, and Cohen-Coon are among a few of the methods used to find the gain values of the controller.

In the year 1996, the idea of linear and non-linear state space controllers for the MagLev system was proposed. The linear controller was based on linearization of the feedback [5]. The transformation of a non-linear state space with a state feedback is used for linearizing the system. The position tracking error of the oscillations of the system was about ± 0.45 mm.

Before applying any controller in stabilizing the system, the system has to be linearized. Then, the controllers are implemented with the application of various algorithms. For instance, optimal PID controllers have been designed for the MagLev system in which we have observed both fractional and integer order for the linearized model [6].

When stabilizing and controlling a single axis magnetic levitation system, Dan Cho and colleagues studied sliding mode controllers versus classical controllers[7]. They also noted that sliding mode controllers provide more damping than classical controllers do. A second-order sliding mode controller has also been implemented in order to stabilize the system and reject the noise and disturbances inside the system [8]. A sliding mode controller has been implemented to control the amount of the current controlling the amount of magnetic field.

For a Maglev system with a time delay, Sirsendu S. M., et al. developed a PID controller based on the Coefficient Diagram Method [9] . The CDM-PID controller's parameters are adjusted using algebraic-based techniques. The transient performance and error indices have improved as a result of the proposed controller.

Sum of Squares (SoS) technique was used by Bhawna T to analyse the stability of a Maglev system based on a nonlinear controller [10]. Applying SoS to the Maglev System must necessitate a nonlinear controller. Rosalia H. Subrata to stabilize floating items in Maglev systems created a PID controller [11]. It is important to consider the unstable nonlinear dynamics of the maglev system. The controller goes a long way in stabilising the system by considering nonlinear dynamics. A. S. C. Roong created a model-based feed-forward PI-PD controller for the position tracking of the Maglev system. However, for every disturbance, this controller needs a sensor and a model [12].

An evolving Takagi-Sugeno (T-S) fuzzy model was put forth by R. E. Precup to describe the nonlinear dynamics phenomena that take place in the location of Maglev systems [13]. Prior to using a linearization strategy to stabilise the nonlinear process at specific operating points, a state feedback control structure must be designed. An adaptive control algorithm was put forth by B. Singh for the MRAC technique-based location tracking of a real-time Maglev system [14]. Finding the adjustment mechanism so that a stable system reduces the error to zero is a crucial issue with the MRAC system. In the MRAC technique, the PID controller's parameters are automatically updated.

For the Maglev system, K. H. Su suggested fuzzy and supervisory fuzzy models based on gradient descent technique [15]. In the suggested approach, the mathematical model of the Maglev system is swapped out for a fuzzy model in order to improve tracking, lessen chattering, and improve transient responsiveness. Following experimental validation, Ahmed El Hajjaji created a non-linear model for the magnetic levitation system [16]. A non-linear control rule based on differential geometry was then created and applied in real time.

An indirect technique for self-tuning PID controller gains for a digital excitation system was put forth by Kim K [17]. The Recursive Least Square (RLS) estimate method is used in the suggested way to fine-tune the PID controller's parameters. When the closed loop is in a steady state and being controlled by a PI controller, the loop gain is estimated. RLS is used to identify the exciter and generator's time constants. A controller based on an adaptive finite impulse response (FIR) filter was created by M Shafiq et al. [18] for the tracking of a ferrous ball while it is being affected by magnetic force. Along with the PID controller, an adaptive FIR filter is implemented to increase stability. The controller maintains stability because the adaptive FIR filters are intrinsically stable.

For an active magnetic bearing system, Chang, Wu created a straightforward implicit generalised predictive self-tuning control based on the Controlled Auto-Regressive Integrated Moving-Average (CARIMA) model [19]. The suggested control technique is an innovative approach to remote predictive control that ensures the stability of an open loop unstable system by fusing the benefits of several algorithms collectively. A state feedback controller and model predictive controllers (MPCs) were created by S. Sgaverdea for the position control of a sphere in a magnetic levitation system. Using state feedback control is developed initially to keep the system stable [20]. The second controller was created based on MPC in the outer control loop to guarantee there were no steady-state control faults.

Different non-linear controllers were developed by M. Ahsan for position tracking in a magnetic suspension system in the face of parametric uncertainties and external disturbances [21]. Lyapunov's stability analysis and feedback linearization were used to design an adaptive linear and nerocontroller for the Maglev System by A. Rawat [22]. The closed loop system is stable thanks to a combination of an adaptive rule and a feedback linearizing control law. I. Mizumoto edeveloped an adaptive PID controller for a magnetic levitation system using an almost strictly positive real (ASPR)-based parallel feedforward compensator (PFC) [23]. When the input is saturated, the static PFC exhibits a windup phenomenon and its control performance suffers.

C. S. Chin designed the prototype microprocessor controlled hybrid magnetic levitation and propulsion system (MCLEVS) for conveyance purposes, consisting of a linear synchronous motor and a hybrid electromagnetic levitation [24]. C. S. Teodorescu discussed the analytical solutions and treat systematically feasibility, stability and optimality issues in a Maglev system [25]. It is very important to understand dynamic behavior of system. J. H. Yang proposed a modeling equipment for Maglev system and an automatic algorithm for making the 2D lookup table from the experimentally measured data [26]. Modeling equipment measures the magnetic force exerted on the levitation object, the coil current of electromagnet and the distance between the levitation object and the electromagnet.

An Analog controller suspension model has also been implemented along with the PID controller [27]. Another optimization algorithm used Grey Wolf Optimization for tuning the PID gain values [28]. With the help of teaching learning-based methods of optimization, time domain, and frequency domain parameters can be improved after minimizing the objective function [29]. LQR-PID controller was also implemented to control the maglev system [30]. But a deep knowledge of the mathematical model is needed in deciding the weight of the matrix R and Q in LQR controller implementation. To reduce the overshoot, non-linear controllers have been designed with changes in the damping ratio [31]. A combination of PID, Fuzzy, and LQR controllers has also been implemented for the maglev system [32].

PSO-PID control scheme was designed for balancing and propulsive positioning of a maglev system [33]. The control of the position of the ball was carried out using LQG based controller in order to manipulate the current of the electromagnet for driving the ball to a steady state with a minimal rate of error [34]. The extremum seeking (ES) method was used to tune PID parameters to improve steady-state response with minimum oscillations [35]. The cuckoo search fractional order PID (CSFOPID) controller was outlined to balance out the maglev framework [36].

An analog controller has also been used to model the system in a controlled environment which in turn uses a PID controller by using the pole-assigned method [37]. Predictive fuzzy PID along with PSO has been implemented to focus on poor robustness [38]. Sliding mode surface along with time delay compensation and a double-layer neural network along with adaptive laws have been implemented to stabilize the controller [39].

Fuzzy Sliding Mode Controller (FSMC) applied in order to make the system achieve asymptotic stability. This controller is helpful as the details are not required. In addition, Novel Fuzzy Sliding-Mode Control (NFSMC) has been applied to study the comparison effect of uncertainty in the ball mass between SMC, FSMC and NFSMC [40].

Machine Learning concepts have also been used for an adaptive neural controller that has been implemented which has input delays compensation. For that implementation, a optimization method with controlled parameter has been implemented. Projection Recurrent Neural Network based adaptive backstepping control approach has also been implemented for stabilizing the system and adjusting the position of the ball [41].

A Manta Ray Foraging Optimization (MRFO) has been implemented in addition with, opposition-based learning method and a Nelder–Mead (NM) to outline a new developed algorithm which is known as the Novel Improved Manta Ray Foraging Optimization [42].

CHAPTER 3

MODELLING OF MAGLEV SYSTEM

3.1 MAGLEV MODEL

In this section, an electrical-mechanical model and the control aspect of the maglev model will be discussed. A project starts with the modelling of the plant and the electrical-mechanical model is shown in the figure 3.1 [43].

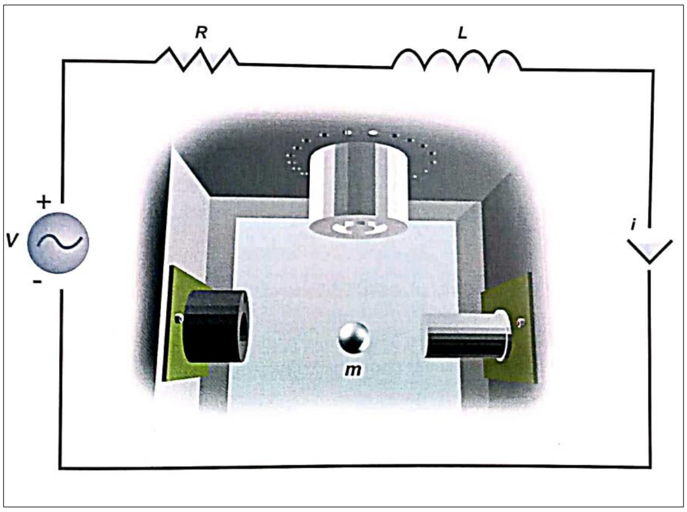

Figure 3.1 Electro-mechanical model of Maglev System

Usually, the models are non-linear in nature. At least one of the states (i- current or x- ball position) is an argument for the function which is non linear. Thus the model needs to be linearized in order to be presented as a transfer function. The linearization has been discussed in details later on.

3.2 HARDWARE SETUP OF MAGLEV

Magnetic levitation setup plant consists of these important parts

a) **Electromagnetic coil :** When current is run through electromagnetic coils, they produce the required magnetic field. The metallic object interacts with the created field to produce the required lifting force.

b) **Infrared light Sensor:** The IR sensor is composed of two elements. One is an IR light transmitter, while the other is an IR light receiver. When an object is suspended, parts of the lights are obstructed, which causes a proportional increase in voltage. The quantity of voltage generated reveals the object's position.

c) **Metal Object:** Here, a metallic hollow ball is regarded as an object. The ball is about 20 grams in weight.

d) **Analogue and Digital interface:** Since a computer operates in the digital domain while a maglev plant operates in continuous time, the two devices are connected via analogue and digital interfaces. Therefore, an interface is required to couple the two.

e) **Controller:** The open loop stability of the maglev plant. So a controller is required in order to perform levitation. Advantech PCI1711 card is used to connect the required controller to the Maglev system. The controller is designed in MATLAB or 14 Simulink. The limit for the control output is between +5V and -5V [44].

Figure 3.2 Maglev System

3.3 MATHEMATICAL MODELLING OF MAGLEV

The Maglev system is a non-linear model and the dynamics of the metallic ball under the electromagnetic field is given by equation 3.1:

$$m\ddot{x} = mg - f_e \qquad (3.1)$$

Where f_e is magnetic force and given by:

$$f_e = k_1 \left(\frac{i^2}{x^2}\right) \tag{3.2}$$

Substituting value from equation 3.2 in 3.1, we get:

$$m\ddot{x} = mg - k\left(\frac{i^2}{x^2}\right) \tag{3.3}$$

$$i = k_2 u \tag{3.4}$$

Where, k_1 = constant depending on the coil

$\mathrm{k_2} = \text{input conductance}$

x = ball position

u = controlling voltage

m = mass of metallic ball

g = Earth's gravitational force

The above non-linear model can be linearized as below:

$$\ddot{x} = -\frac{\partial \mathrm{f(x,i)}}{\partial \mathrm{i}}\Big|_{io,xo} \Delta\mathrm{i} - \frac{\partial \mathrm{f(x,i)}}{\partial \mathrm{x}}\Big|_{io,xo} \Delta\mathrm{x} \tag{3.5}$$

$$\ddot{x} = -\frac{2ki_o}{mx_o^2}\Delta\mathrm{i} + \frac{2kx_o^2}{mx_o^3}\Delta\mathrm{x} \tag{3.6}$$

Equilibrium points are calculated by calculating values at $\ddot{x} = 0$,

$$g = f(x,i)|_{xo,io} \tag{3.7}$$

$$g = \frac{ki_o}{mx_o^2} \tag{3.8}$$

Substituting values from equation 3.8 in equation 3.6, obtained equation

$$\ddot{x} = -\frac{2g}{i_o}\Delta\mathrm{i} + \frac{2g}{x_o}\Delta\mathrm{x} \tag{3.9}$$

Take , $k_i = \frac{2g}{i_o}$ and $k_x = -\frac{2g}{x_o}$, we obtained equation

$$\ddot{x} = -k_i\Delta\mathrm{I} - k_x\Delta\mathrm{x} \tag{3.10}$$

After applying Laplace Transform, we get

$$\frac{\Delta x}{\Delta \mathrm{i}} = -\frac{k_i}{s^2 + k_x} \tag{3.11}$$

Taking equilibrium points: xo= -1.5V (0.009m) and io= 0.8A and finding k_i and k_x and finally putting their values in equation 3.11, we obtain equation 3.13.

$$V = 143.48x - 2.8 \tag{3.12}$$

$$G(s) = \frac{-24.525}{s^2 - 2180} \tag{3.13}$$

Voltage and current are related as

$$i = 1.05 * v \tag{3.14}$$

Measured output sensor is calculated as:

$$x_v = 143.48x_m - 2.8 \tag{3.15}$$

3.4 BLOCK DIAGRAM OF MAGLEV

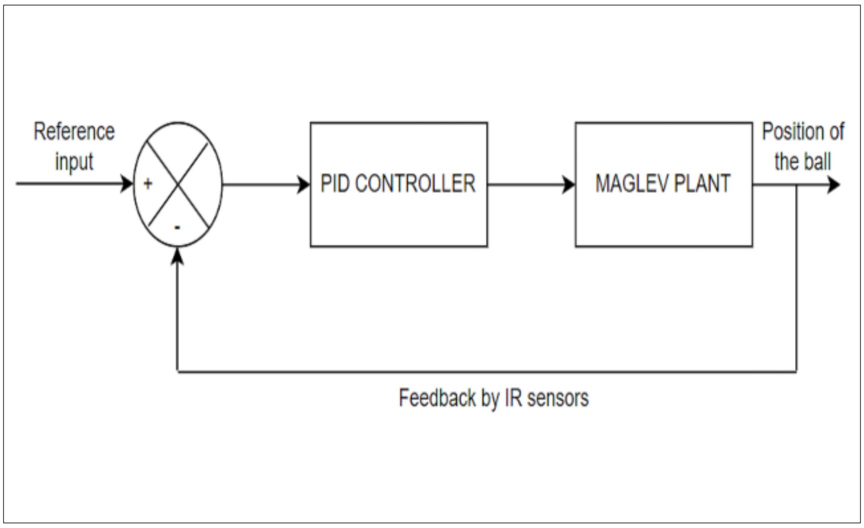

Figure 3.3 Block Diagram for Maglev

We have a feedback controller in the system to minimize the error between the reference signal and the output. The output is a function of the x i.e. ball position which in turn is converted to voltage internally and which is again compared with the reference signal i.e. we define as error. The error here is Integral Square Error, which is fed in the controller to be minimized.

CHAPTER 4

DESIGINING OF CONTROLLERS FOR MAGLEV

4.1 FEEDBACK CONTROLLERS

A feedback controller gauges the process's output before adjusting the input as necessary to move the process variable closer to the intended setpoint. A controller responds to both operator-initiated setpoint adjustments and erratic process variable disturbances brought on by outside sources. This cycle of measuring, deciding, and acting is repeated until the process variable reaches the setpoint.

The controller can't change the process variable right away because of the process's inertia, so it has to settle for "close enough" at least for the foreseeable future. The exact level of proximity is determined by the controller's design, which typically takes into account the amount of slack that is acceptable for a given application.

Designing a controller to periodically improve one of these exhibition gauges involves numerical models of interactions, individualized recovery programs, and replicated experiments. The designer repeats this trial-and-error process, either manually or under computer control, until the degradation of performance measurements is no longer imminent. The final set of tuning parameters can then be loaded into the actual controller to bring the actual process variables closer to their setpoints under real operating conditions [45].

4.2 PD CONTROLLER

This type of controller in a control system whose output varies proportionally to both the error signal and the derivative of the error signal, is known as a proportional derivative controller. This type of controller offers the combined effect of both proportional and derivative control actions [46].

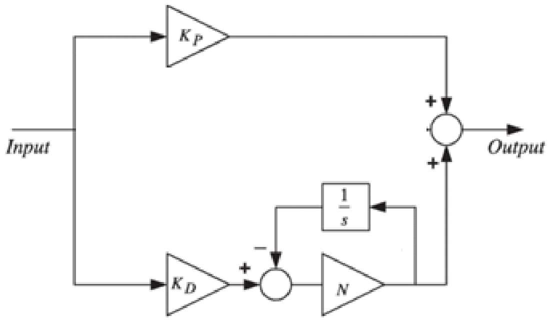

Figure 4.1 PD Controller

In this case, the control signal is proportional to both the error signal and the integral of the error signal. The mathematical expressions for proportional and integral controllers are given by Equation (4.1) where e(t) is the error between the reference input and the output obtained.

$$m(t) = K_p e(t) + K_d \frac{d}{dt} e(t) \quad (4.1)$$

The control effect of the differential controller was used separately in the control system. However, merging the proportional controller with the derivative controller yields a more efficient system. Here, proportional controllers eliminate the drawbacks associated with differential controllers.

It turns out that differential controllers are basically designed with the goal of changing the output as the error signal changes. However, it does not change for a constant error signal. This is because the rate of change over time is 0 if the value of the error signal remains constant. So we use a differential controller in combination with a proportional controller to account for even constant error signals.

The presence of a derivative control action with a proportional controller increases sensitivity. This helps generate an early corrective response even with small values of the error signal, increasing system stability. However, we are also aware of the fact that the derivative controller increases the steady-state error. On the other hand, proportional controllers reduce steady-state errors.

4.4 PID CONTROLLER

A type of controller in which the output of the controller varies proportionally to the error signal, the integral of the error signal, and the derivative of the error signal is known as a proportional-integral-derivative controller. PID is an acronym for this type of controller [47].

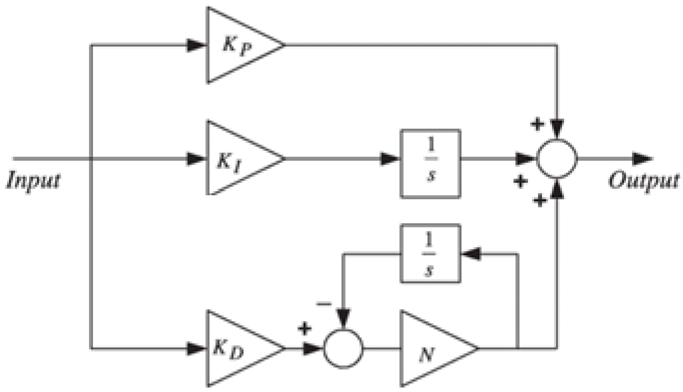

Figure 4.2 PID Controller

Combining all three types of control actions improves the overall performance of the control system and provides the desired output in an efficient manner. The output of the PID controller is specified as Equation (4.2) where e(t) is the error between the reference input and the output obtained.

$$c(t) = K_p e(t) + K_i \int e(t) + K_d \frac{d}{dt} e(t) \tag{4.2}$$

We already know that in PI controllers, the combined action of proportional and integral controllers reduces the steady-state error and thus acts as a beneficial factor for the overall control system. Therefore, the steady-state operation of the whole system is improved. However, in this case, the stability of the system remains unchanged, as no improvement is observed.

We also recognize that the PD controller increases the sensitivity of the system. This is because in this case the controller output changes proportionally to the error signal and the derivative of the error signal. Therefore, even if the rate of change of error is small, you will see large fluctuations in the output.

In this way, an early corrective response of the system is generated, thereby improving the overall system stability. However, a notable feature of PD controllers is that the steady-state error is unaffected. More simply, we can say that a derivative controller leads to a steady-state error. Stability errors occur with integrated controllers. PID controllers are used to overcome the respective drawbacks of both controller types. Therefore, PID controllers create systems with improved stability and reduced steady-state error.

4.4 PID PLUS DOUBLE DERIVATIVE CONTROLLER

A genuine PID plus second-order derivative (PIDD2) controller, a modified form of the PID controller has recently been put out that can offer higher order systems smoother and quicker reactions while maintaining appropriate overshoot and settling time bounds .

A more modern variation of the commonly used PID controller that increases phase margin, steady state accuracy, and plant stability is the real PID plus second-order derivative (PIDD^2) controller. K_p, K_i, K_{d1} and K_{d2} are proportional, integral, derivative, and second-order derivative gains, respectively, the real PIDD^2 controller can be expressed. Additionally, N_1 and N_2 stand for the filter coefficients [48].

$$c(t) = K_p e(t) + K_i \int e(t) + K_{d1} \frac{d}{dt} e(t) + K_{d2} \frac{d}{dt} (\frac{d}{dt} e(t)) \qquad (4.3)$$

The block diagram of a genuine PIDD2 controller is shown in Figure 4.3.

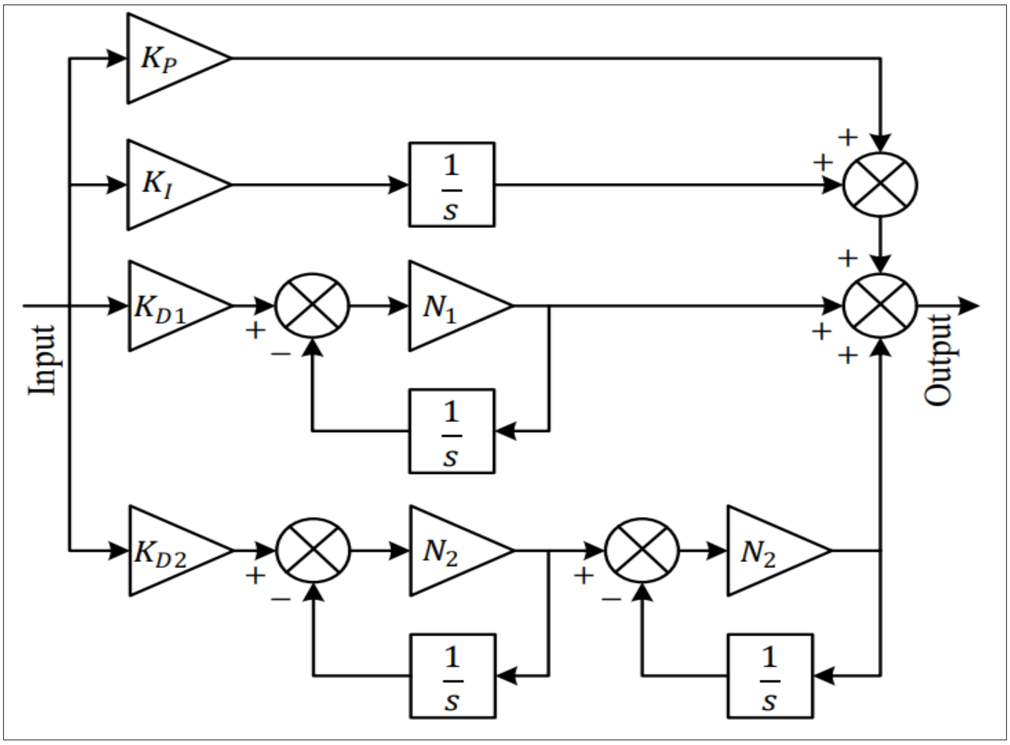

Figure 4.3 PIDD^2 Controller

CHAPTER 5

OPTIMIZING ALGORITHMS

5.1 GENETIC ALGORITHM

Genetic algorithm is a method of solving constrained and unconstrained optimization problems based on natural selection, the process that drives biological evolution. A genetic algorithm iteratively modifies the population of a single solution. At each step, the genetic algorithm selects individuals from the current population as parents and uses them to generate the next generation of offspring.

Over generations, the population "evolves" toward the optimal solution. Genetic algorithms can be applied to solve various optimization problems that are not well suited to standard optimization algorithms. This includes problems where the objective function is discontinuous, non-differentiable, stochastic, or strongly nonlinear. Genetic algorithms can deal with mixed integer programming problems where some components are constrained to integers.

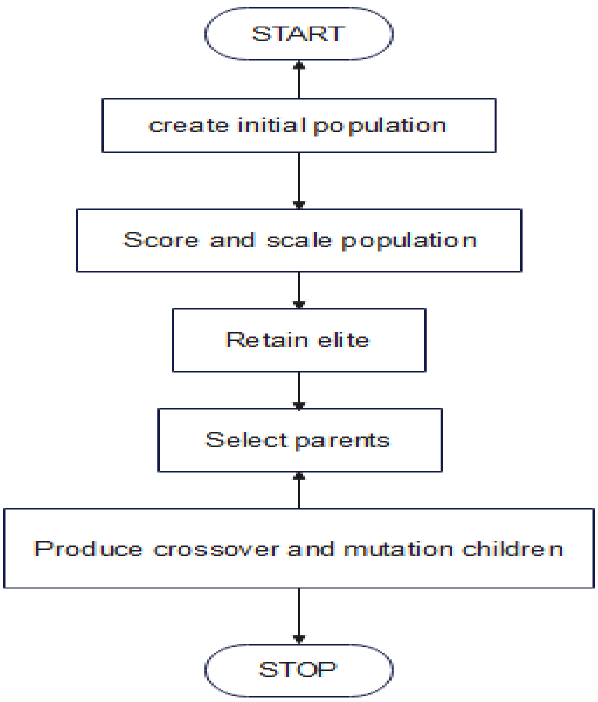

Figure 5.1 Genetic Algorithm Flowchart

The following overview summarizes how the genetic algorithm works.

1. The algorithm creates a random initial population.
2. The algorithm creates a set of new populations after step 1. At every step, the algorithm uses the current generation of individuals to create the next population. The algorithm performs the following steps to create a new population.
    2.1 Calculate the fitness score and score each member of the current population. These values are called raw fitness values.
    2.2 Scale the raw fitness values into a more usable range of values. These scaled values are called expected values.
    2.3 Based on your expectations, select a member called Parent.
    2.4 Some individuals with low fitness in the current population are selected as elites. These elite individuals are carried over to the next population.
    2.5 Give birth to a child from a parent. Children are created by random alterations to a single parent (mutation) or by combining vector entries of paired parents (crossover).
    2.6 Replace the current population with children to form the next generation.
3. The algorithm stops when one of the stopping criteria is met.
4. The algorithm performs modified steps for linear and integer constraints.
5. This algorithm is further modified for nonlinear constraints

GA toolbox provided has been used to find out gain values of the controllers. An objective function has been defined in which the error is made to minimize with 10 generations [49].

5.2 PARTICLE SWARM OPTIMIZATION

Particle swarm optimization (PSO) is one of the biologically-inspired algorithms that can easily find the best solution in the solution space. It differs from other optimization algorithms in that it only requires an objective function and does not depend on the gradient or differential form of the objective function. It also has few hyper parameters.

Particle Swarm Optimization was proposed by Kennedy and Eberhart in 1995. As mentioned in the original paper, sociobiologists believe a school of fish or a flock of birds that moves in a group “can profit from the experience of all other members”. In other words, while a bird flying and searching randomly for food, for instance, all birds in the flock can share their discovery and help the entire flock get the best hunt [50].

We can simulate the movement of a flock of birds, but each bird is designed to help find the best solution in a high-dimensional solution space, and the best solution found by the flock is the You can also imagine that it is the best solution. This is a heuristic solution. Because it cannot be proved that a real global optimum is found, and usually not. However, the solution found by PSO is often very close to the global optimum [51].

All PSO algorithms are pretty much the same as above. In the example above, we set the PSO to run with a fixed number of iterations. It's easy to set the number of iterations to run dynamically based on progress. For example, you can stop as soon as you no longer see updates to Global Best Solutions. Repeat several times. Research on PSO has mainly concerned the determination of hyper parameters. w, c_1, and c_2. Or change their values during the course of the algorithm. For example, there are proposals to linearly decrease inertial weight. There is also a proposal to create a cognitive coefficient while the social coefficient is decreasing. Gradually brings more exploration at the beginning and more exploitation at the end [52].

In particle swarm optimization

$$v_i^{t+1} = v_i^t + \emptyset_1 U_1^t (pb_i^t - x_i^t) + \emptyset_2 U_2^t (gbt^t - x_i^t) \tag{5.1}$$

In Modified particle swarm optimization

$$v_i^{t+1} = wv_i^t + \emptyset_1 U_1^t (pb_i^t - x_i^t) + \emptyset_2 U_2^t (gbt^t - x_i^t) \tag{5.2}$$

$$x_i^{t+1} = x_i^t + v_i^{t+1} \tag{5.3}$$

While going through iteration process the value of inertia weight updating by

$$w = w_{max} + \left[\frac{(w_{max} - w_{min})}{iter_{max}}\right] * iter \tag{5.4}$$

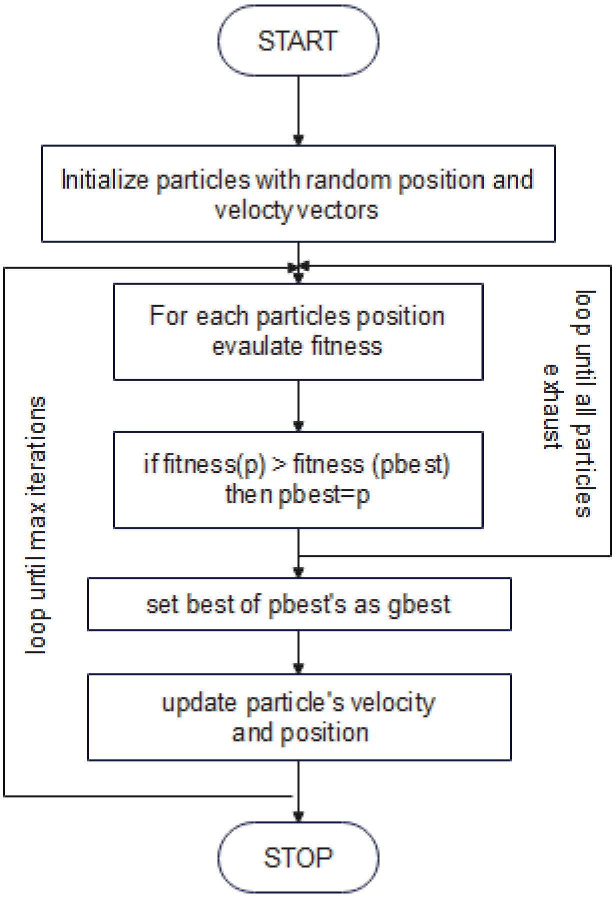

Figure 5.2 PSO Flowchart

5.3 GIZA PYRAMIDS CONSTRUCTION ALGORITHM

GPC is a metaheuristic algorithm. It is based on an ancient inspired ideology [18]. As there were restrictions and was lack of capabilities for optimization, thus, optimization of the construction of pyramids was developed in ancient Egyptian society. This optimization of pyramids led to a considerable decrement in construction costs and provided an optimized workforce management.

The stone blocks were collected and these were made to be transported to the installation site by creating ramps. Ramp gradient, initial velocity and frictional forces are the factors that have an effect on the transportation of the stones. The workers continuously change their position in order to get hold of the stone. The best performing worker is known as Pharaoh's special agent. Worker's position and stone both are responsible in deriving the solution.

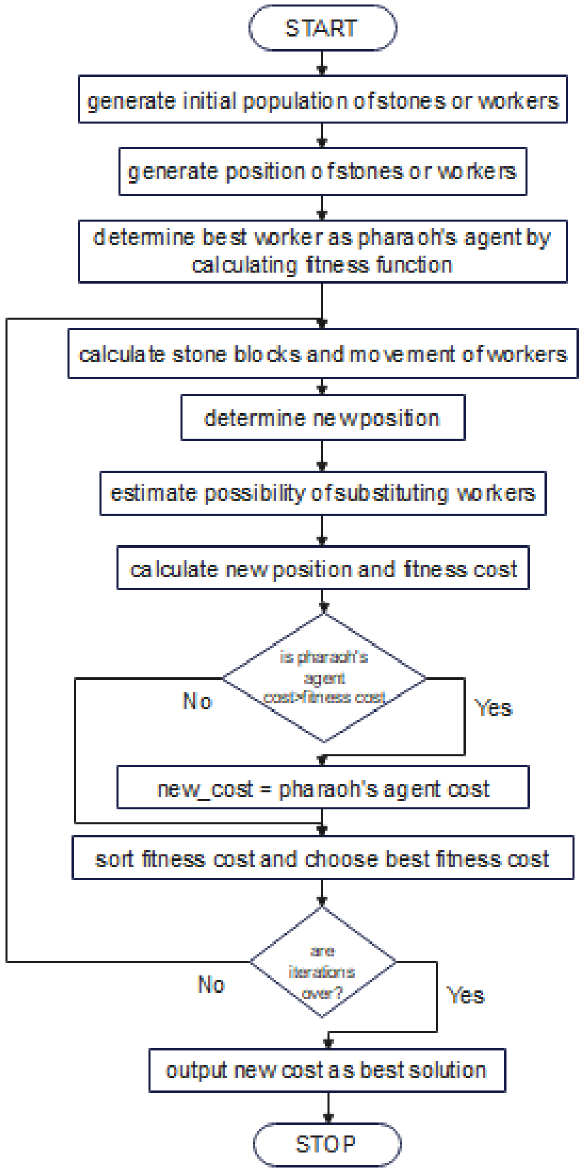

Fig 5.3 GPC algorithm flow chart

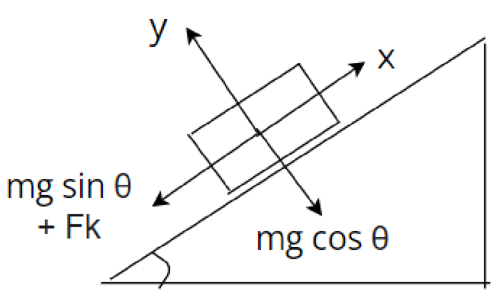

Figure 5.4 Forces acting on the body

Equation 5.5 determines the amount of displacement made by stone on the ramp from its previous position.

$$d = \frac{v_0^2}{2g\,(\sin\,\theta + \mu_k\,\cos\theta)} \tag{5.5}$$

Where, v_0= initial velocity of the block

g =gravity acting on earth,

θ = angle that the ramp makes with the horizon

μ_k = kinetic friction coefficient.

Equation 5.5 is modified in determining the new position of the worker. Friction is not taken into consideration in the case of the worker. Hence, the new position of the worker, pushing the stone block is given by equation 5.6.

$$x = \frac{v_0^2}{2g\,\sin\,\theta} \tag{5.6}$$

New position obtained from equations 5.5 and 5.6 is given by equation 5.7

$$\vec{p} = (\vec{p}_i + d) \times x\,\vec{\in}_i \tag{5.7}$$

Where, $\vec{p}_i$ =current position,

d = stone block displacement value,

x= amount of worker movement

$\vec{\in}_i$= random vector follows Uniform, distribution.

The substitution operation is performed with 50% probability at default.

If the primary solutions are

$\emptyset = (\varphi_1, \varphi_2, \dots \dots, \varphi_n)$

and the generated solutions are

$\boldsymbol{\psi} = (\psi_1, \psi_2, \dots \dots, \psi_n)$,

then the new solutions are substitution will be

$\boldsymbol{\xi} = (\xi_1, \xi_2, \dots \dots, \xi_n)$.

The substitution condition is written as

$$\xi_k = \begin{cases} \psi_{k,} & if\ rand\ [0,1] \leq 0.5 \\ \varphi_k\ , & otherwise \end{cases} \tag{5.8}$$

5.4 HONEY BADGER ALGORITHM

The Honey Badger Algorithm (HBA) is recently developed as a nature-based meta-heuristic method for optimization. This method has been inspired by the methods of preying on the honey badger, a mammal, having a white and black cotton hairy physical appearance with a habitat in semi-deserts, rain forests of Africa, South West Asia along with Indian subcontinent. This mammal has an extensive fearless attribute with intelligent skills for searching and hunting prey. The prey includes dangerous reptiles and food. The Honey Badger algorithm's flowchart is depicted in Figure 5.5.

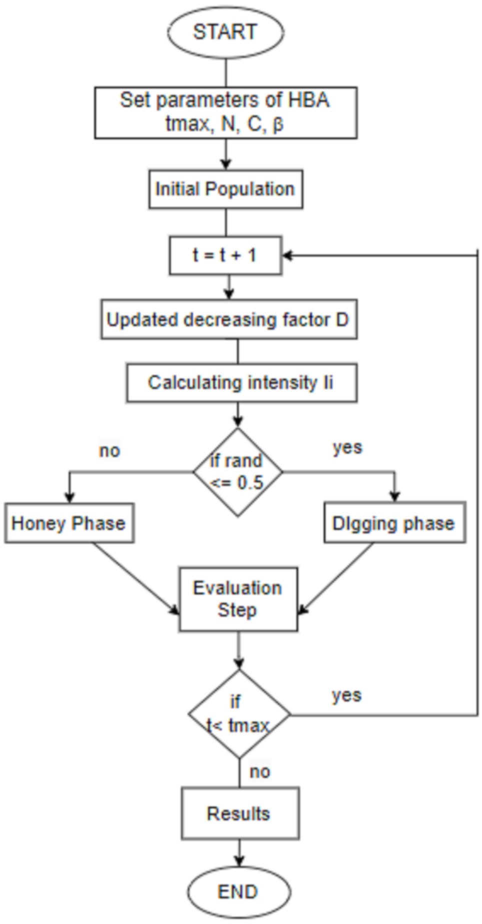

Fig 5.5 HBA flow chart

The proposed technique relies on the honey badger's cunning foraging behavior in the wild, and it exploits this behavior to develop a mathematically effective search strategy for addressing optimization problems. The HBA position updating procedure for finding out the location of the food consists of two steps, which are as follows:

1. To smell the food and dig holes for trapping the food i.e. digging mode
2. Follow a honeyguide bird for finding out the honey i.e. honey mode

Five stages are being followed in HBA to find the optimal solution. These are as follows:

Stage 1: In this stage, the honey badger population's size N and starting positions are initialized.

$$x_i = l_i + r_1 \times (u_i - l_i) \tag{5.9}$$

Where x_i represents ith badger position, u_i and l_i signifies the upper and lower bound of the search space, respectively. The random number r_1 has values between zero and one.

Stage 2: Prey's smell intensity identification

According to the concentration of the prey and the separation between it and the honey badger, the intensity of the search increases. An increased search intensity results from a bigger prey concentration and a closer range. The honey badger is able to locate the prey more quickly due to a strong and powerful stench coming from the prey. This inverse relationship between the search's intensity and the separation between the honey badger and its prey is mathematically represented by equation 5.10.

$$I_i = r_2 \times \frac{s}{4\pi d_i^2} \tag{5.10}$$

Where I_i is the intensity of prey's smell, r_2 is a random number that lies between zero and one. Here, s represents the strength of the source and di shows how far the prey is from the ith badger, as shown by equations 5.11 and 5.12 respectively.

$$s = (x_i - x_{i+1})^2 \tag{5.11}$$

$$d_i = x_{prey} - x_i \tag{5.12}$$

Stage 3: Updating the density factor

The density factor (α) controls the randomization to ensure a smooth transition from exploring a vast search space to looking for the optimum value. Mathematically, the density factor is described in equation 5.13. The variable α can be calculated from the equation 5.13.

$$\alpha = C \times \exp\left(\frac{-t}{t_{max}}\right) \tag{5.13}$$

Where C is a constant value which is higher than one and t_{max} represents max iterations.

Stage 4: Escape from local optimal

Escaping local optima is one of the most difficult problems in function optimization. The proposed approach uses a flag F which is defined in equation 5.15 to change the search's direction, allowing agents to thoroughly scan the search space and steer clear of local optimum solutions.

Stage 5: Process for updating positions in HBA

There are two steps or phases in the process of updating a position.

Digging phase

In this phase, honey badger moves in accordance with the cardioid equation 5.14 below.

$$x_n = x_p + F \times \beta \times I \times x_p + F \times r_4 \times \alpha \times d_i \times |\cos(2\pi \times r_4) \times [1-\cos(2\pi \times r_5)] \tag{5.14}$$

Where x_p is the prey's current, best-known global position. β indicates the badger's ability to locate food. r_4, r_4, r_5 are random numbers that lies between zero and one.

The flag F, which is described as follows, changes the search direction:

$$F = \begin{cases} 1 & if\ r_6 \leq 0.5 \\ -1 & else \end{cases} \tag{5.15}$$

Honey phase:

The honey badger follows the honey guide bird in this phase to get to the beehive. This process is simulated by equation 5.16 as follows.

$$x_n = x_p + F \times r_7 \times \alpha \times d_i \tag{5.16}$$

Where x_n denotes the badger's new location, x_p represents the prey's location. r_7 is a random number that lies between zero and one. Depending on the d_i badger conducts its search process close to x_{prey}.

CHAPTER 6

SIMULATION AND RESULTS

6.1 PD CONTROLLER

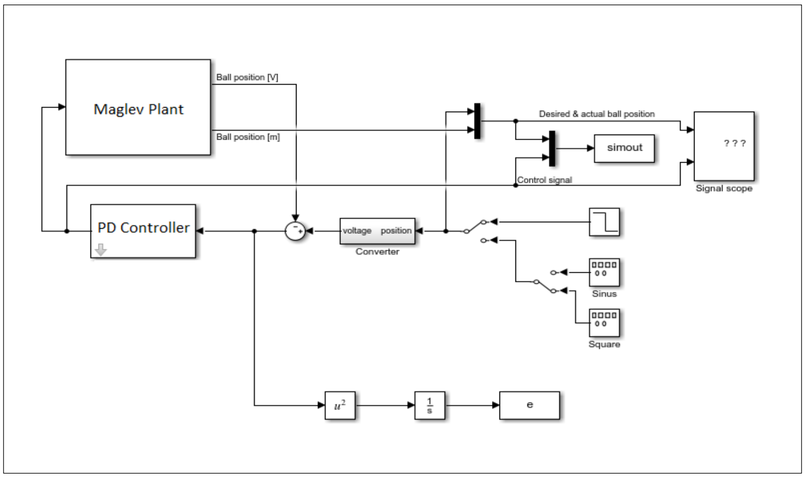

Figure 6.1 Simulink model for PD controller

TABLE 6.1 PD GAIN VALUES

Controller Type	K_P	K_D
GA	8.01	1.71
PSO	8.1442	1.821
HBA	8.0472	0.78
GPC	8.4172	2

The input provided is a step input having an initial value of 0.009 and final value of .0055.

Figure 6.2 depicts the output for step input with PD as controller. The response obtained has been obtained using algorithms like PSO, GPC and HBA. In this case, the best transient response is observed in case of HBA while the other three seems sluggish in response as compared to HBA. The said can be verified in table 6.2 below. While the other parameters are comparable with each other with a large SSE of 16% per average.

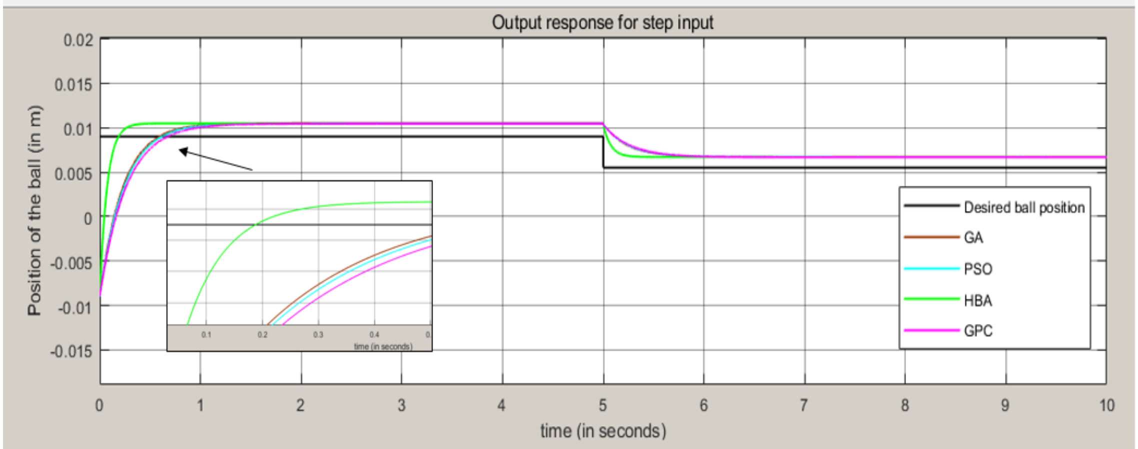

Figure 6.2 Output response for step input (PD)

TABLE 6.2 STEP RESPONSE PARAMETERS

Controller	***Maximum Overshoot***	***Rise time***	***Steady State Error***	***ISE***
GA	.00147	0.546s	16.85%	0.6906
PSO	.00145	0.502s	16%	0.6494
HBA	.00142	0.146s	16.44%	0.6168
GPC	.00141	0.546s	16.11%	0.6342

Figure 6.3 shows the control signal generated to match the changes in the step input and follow the required trajectory.

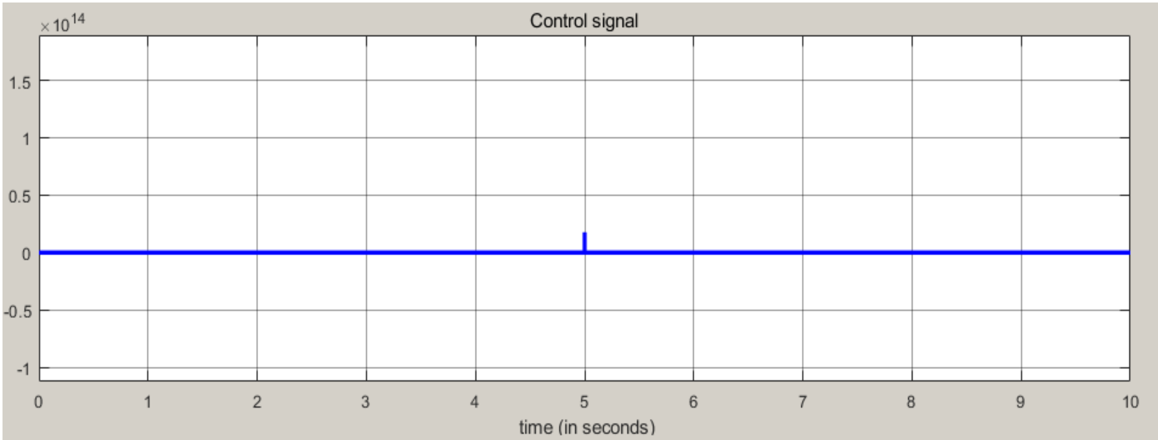

Figure 6.3 Control signal for step input (PD)

Figure 6.4 shows the output response for square input with amplitude of 5 mm. Figure 6.5 shows the control generated to follow the trajectory. Also, in square wave, a closely followed trajectory is observed in the case of HBA while other seems sluggish as compared to other algorithms.

In figure 6.6, a sine input is provided and the response is observed. In this case, GPC is able to provide a better-followed trajectory. Other three are also comparable to GPC.

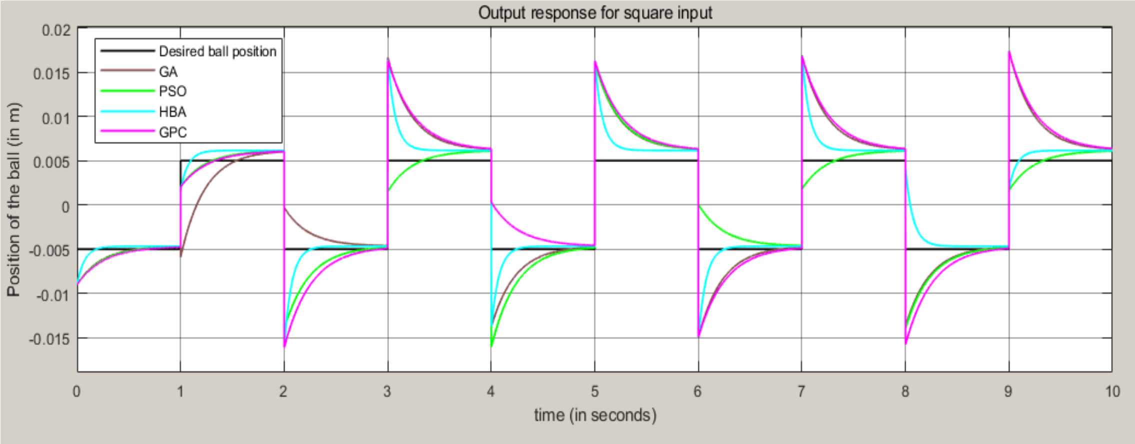

Figure 6.4 Output response for square input (PD)

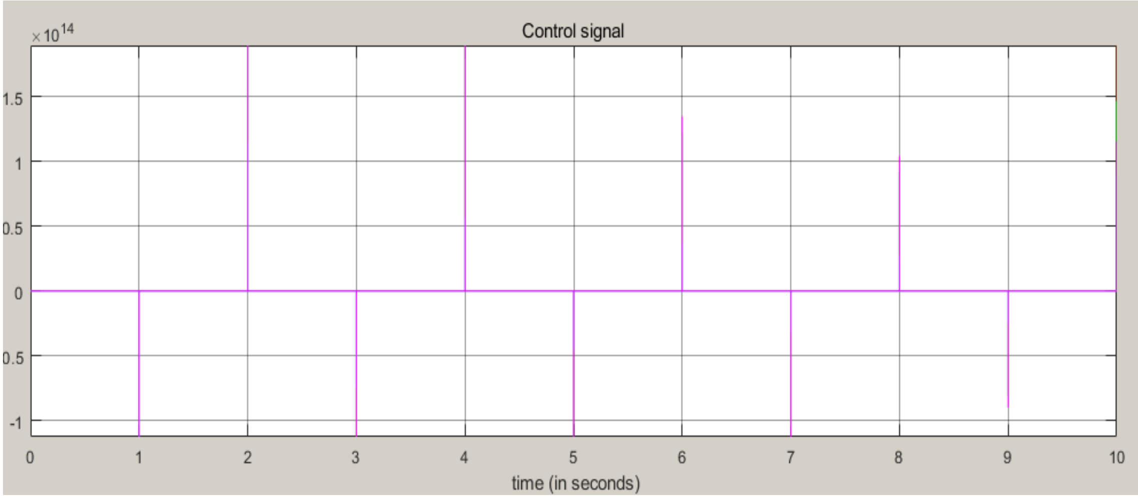

Figure 6.5 Control signal for square input (PD)

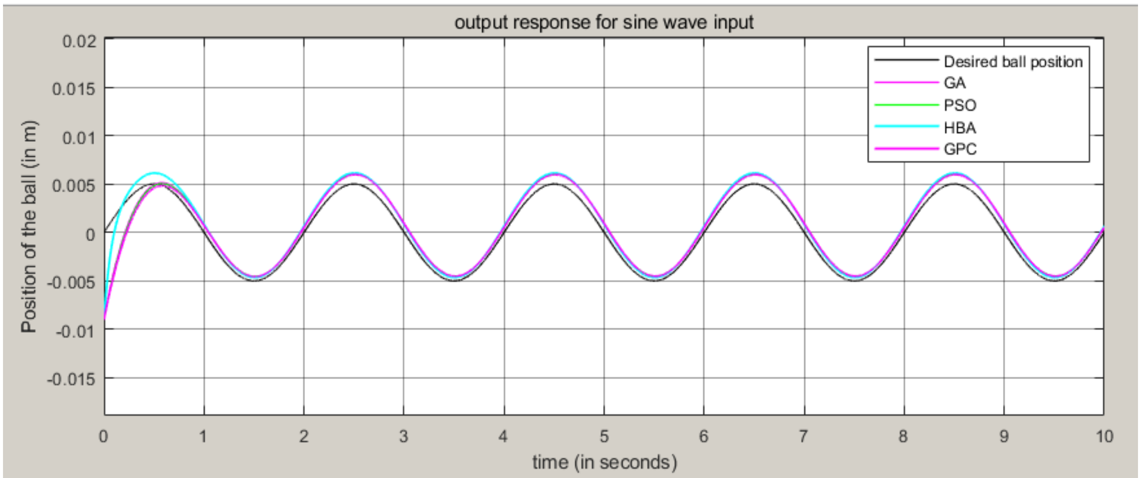

Figure 6.6 Output response for sine input (PD)

6.2 PID CONTROLLER

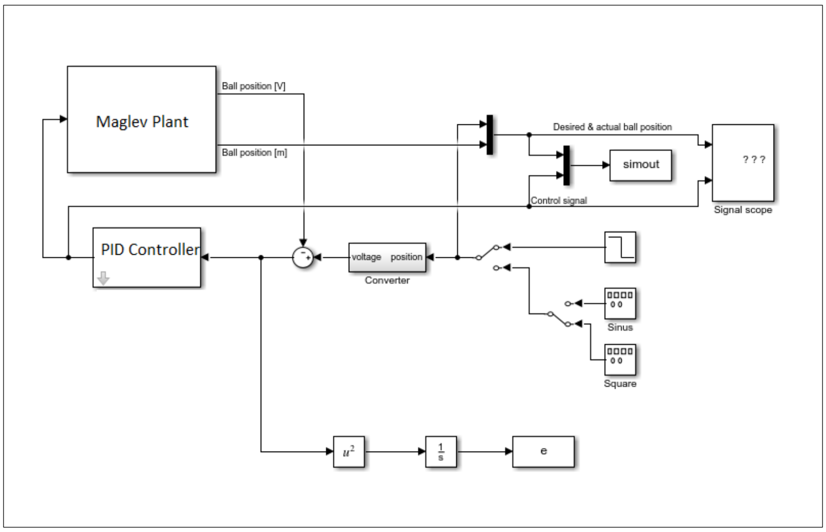

Figure 6.7 Simulink model for PID controller

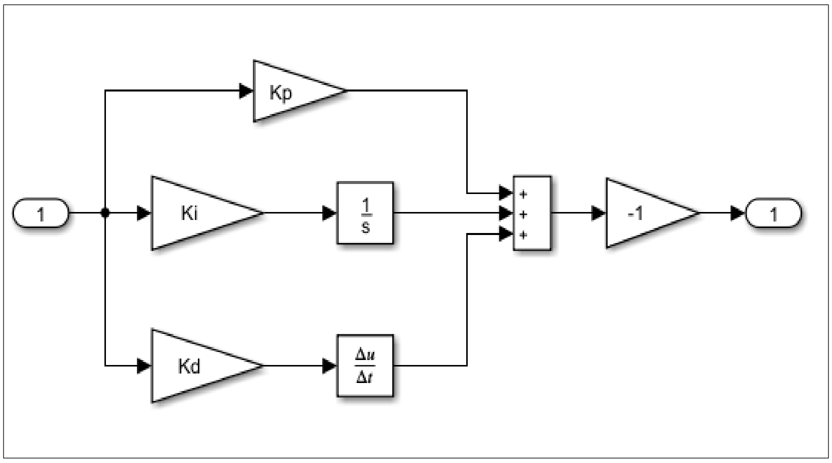

Figure 6.8 PID controller

Table 6.3 shows the gain values of Kp, Ki and Kd of PID controller.

TABLE 6.3 PID GAIN VALUES

Controller Type	K_P	K_I	K_D
GA	14.5099	6.010146	0.151944
PSO	14.72026	7.26669	0.041297
HBA	15	8	0.065
GPC	14.96026	7.668669	0.061297

Figure 6.9 depicts the output for step input with PID as controller. The input provided is a step input having an initial value of 0.009 and final value of .0055.The response obtained has been obtained using algorithms like PSO, GPC and HBA. In this case, the best

transient response is observed in case of GPC. In HBA, we observe a high overshoot while the other two (GA and PSO) seems sluggish in response as compared to HBA and GPC. The said can be verified in table 6.4 below. Settling time (2.714s) is least for GPC and also SSE of .58% is least for GPC while HBA results are comparable with 2.84s settling time and 1.08% SSE.

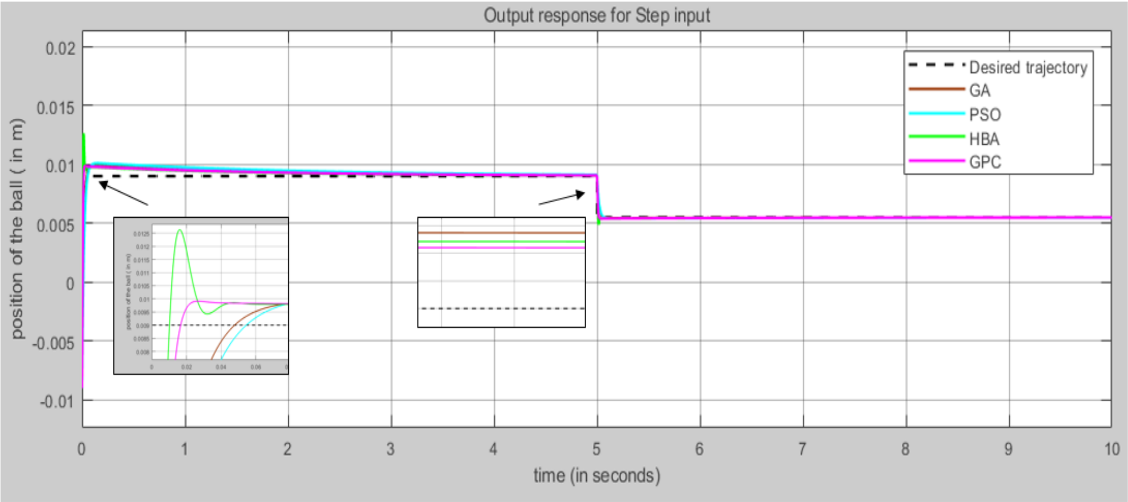

Figure 6.9 Output response for step input (PID)

Table 6.4 shows the step response parameters after the application of PID controller with various algorithms.

TABLE 6.4 STEP RESPONSE PARAMETERS

Controller	***Maximum Overshoot***	***Rise time***	***Settling Time***	***Steady State Error***	***ISE***
GA	.0019	0.096s	----	4.14%	0.0640
PSO	.000855	0.047s	4.174s	1.16%	0.0489
HBA	.00459	0.0099s	2.844s	1.089%	0.0466
GPC	.000927	0.027s	2.714s	0.589%	0.0464

Figure 6.10 shows the output response for square input with amplitude of 5 mm. Figure 6.11 shows the control generated to follow the trajectory. GPC is found to follow the trajectory with less SSE as compared to other three algorithms. While HBA is found better in terms of transient response with less overshoot as compared to other three.

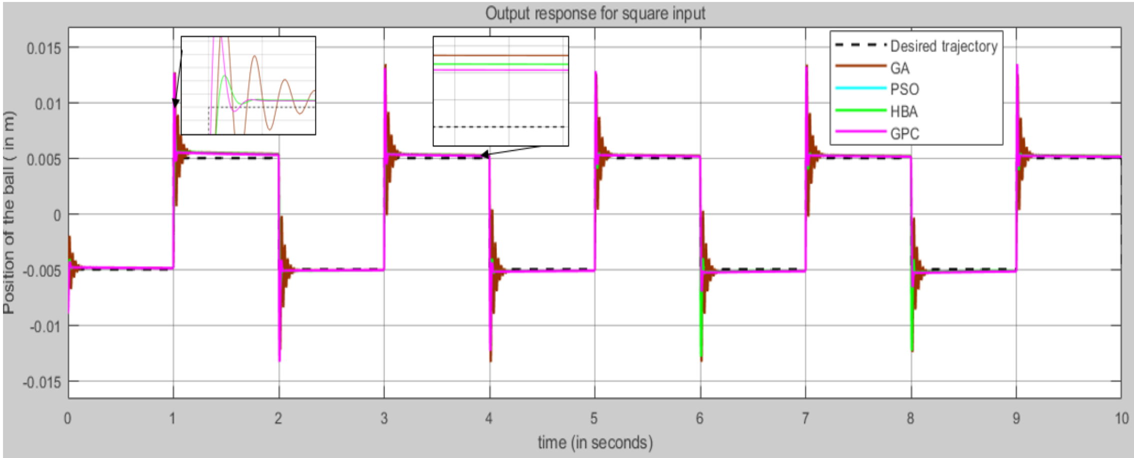

Figure 6.10 Output response for square input (PID)

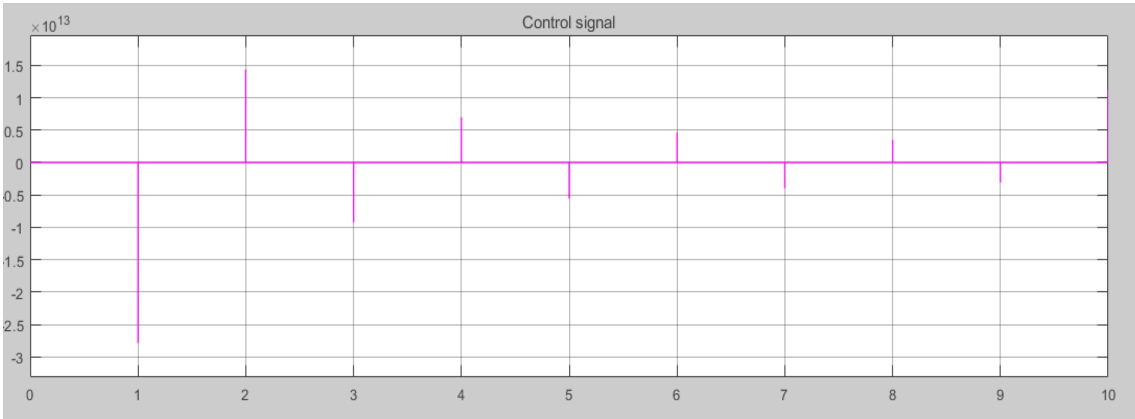

Figure 6.11 Control signal for square input (PID)

In figure 6.12, a sine input with amplitude of 5 mm is provided and the response is observed.

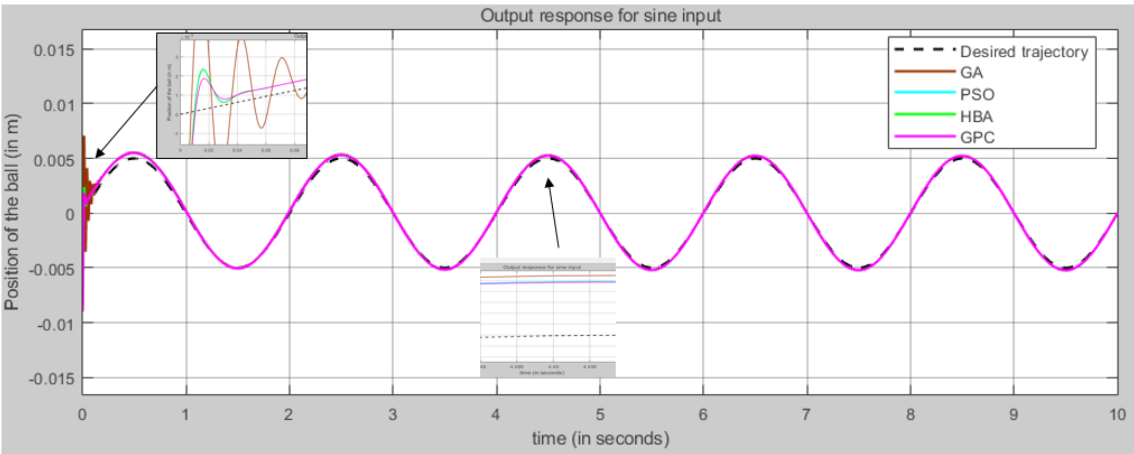

Figure 6.12 Output response for sine input (PID)

6.3 PID PLUS DOUBLE DERIVATIVE CONTROLLER

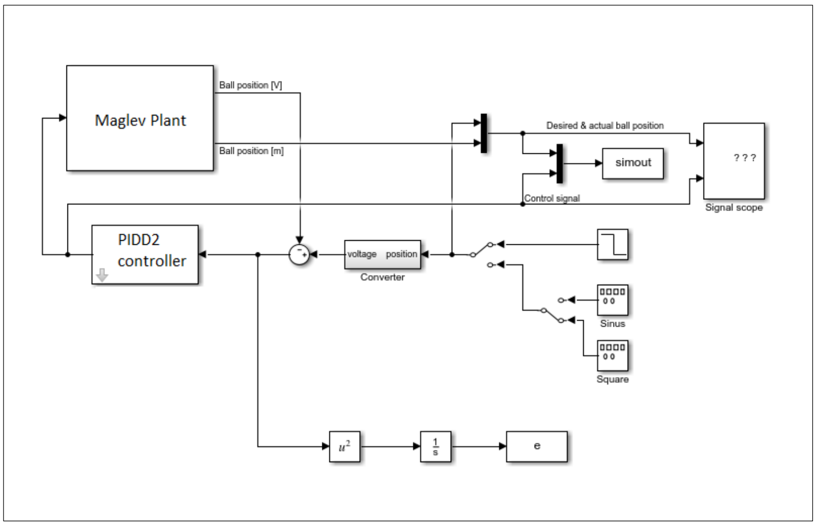

Figure 6.13 Simulink model for PIDD2 controller

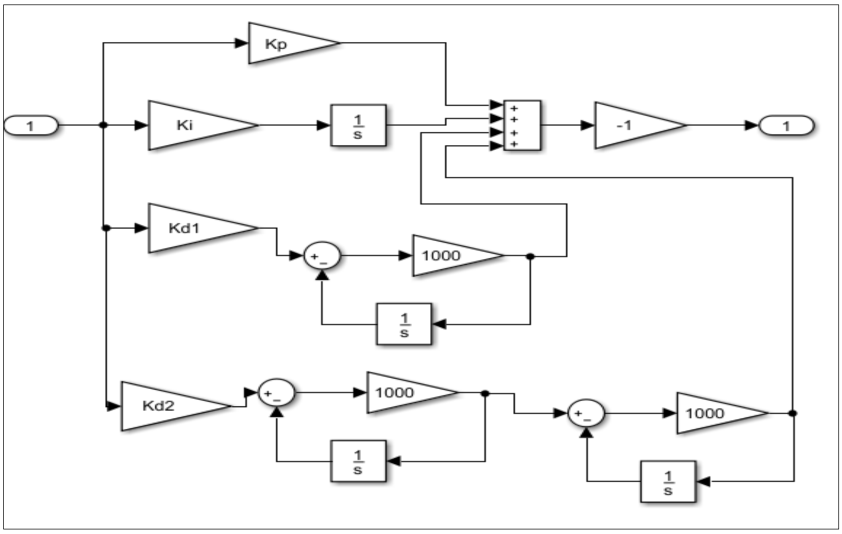

Figure 6.14 PIDD2 controller

Table 6.5 shows the values of gains Kp, Ki, Kd1 and Kd2 for PIDD2 controller.

TABLE 6.5 PIDD2 GAIN VALUES

Controller Type	K_P	K_I	K_{D1}	K_{D2}
GPC (PIDD2)	14.7456	7.584	0.1746	0.000425
HBA (PID)	15	8	0.065	0
GPC (PID)	14.96026	7.668669	0.061297	0

Figure 6.15 depicts the output for step input with PIDD2 as controller. The input provided is a step input having an initial value of 0.009 and final value of .0055. In this case, responses of PID obtained trajectory with HBA and GPC has been compared with PIDD2 controller applied with GPC algorithm. In this response, a better transient response is observed in PIDD2 controller with a rise time of .0099s and settling time of 1.94s and SSE of 0.66%, which is the minimum observed in all three controllers (PD, PID and PIDD2).

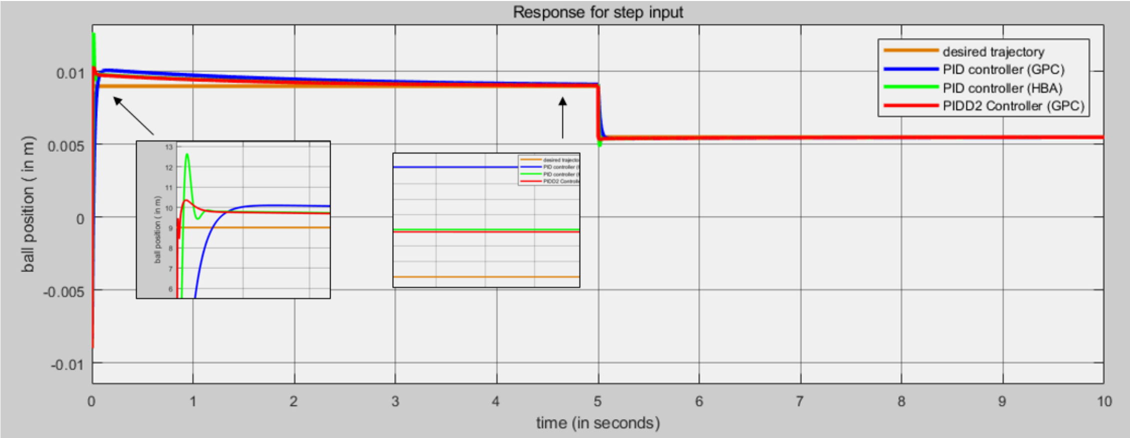

Figure 6.15 Output response for step input (PIDD2)

Table 6.6 shows the step response parameters after the application of PID controller with various algorithms and figure 6.16 shows control signal generated trajectory.

TABLE 6.6 STEP RESPONSE PARAMETERS

Controller	***Maximum Overshoot***	***Rise time***	***Settling Time***	***Steady State Error***	***ISE***
GPC (PIDD2)	.000945	0.0099s	1.94s	0.66%	0.0148
HBA (PID)	.00459	0.018s	2.714s	0.589%	0.0466
GPC (PID)	.000927	0.027s	2.140s	1.8%	0.0464

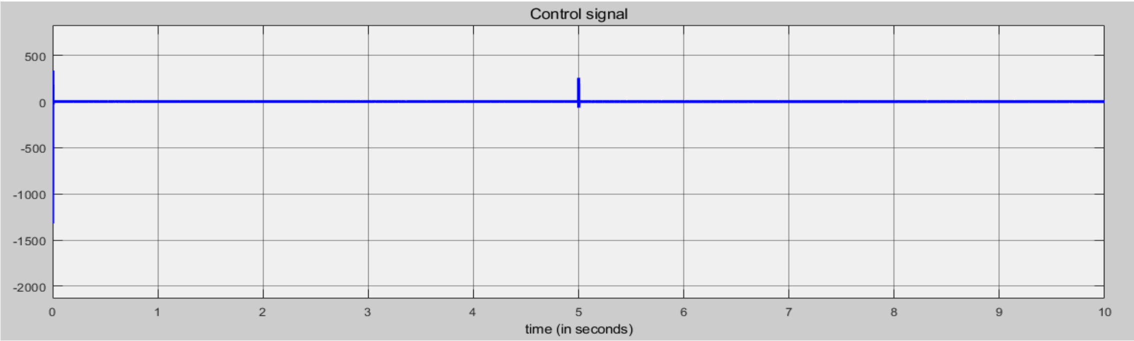

Figure 6.16 Control signal for step input (PIDD2)

Figure 6.17 shows the output response for square input with amplitude of 5 mm. Figure 6.18 shows the control generated to follow the trajectory. PIDD2 is found to follow the trajectory with less SSE as compared to PID.

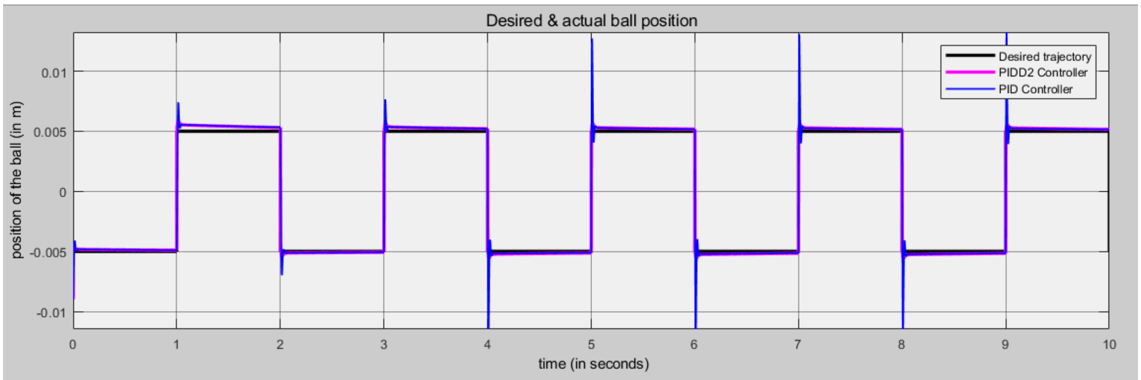

Figure 6.17 Output response for square input (PIDD2)

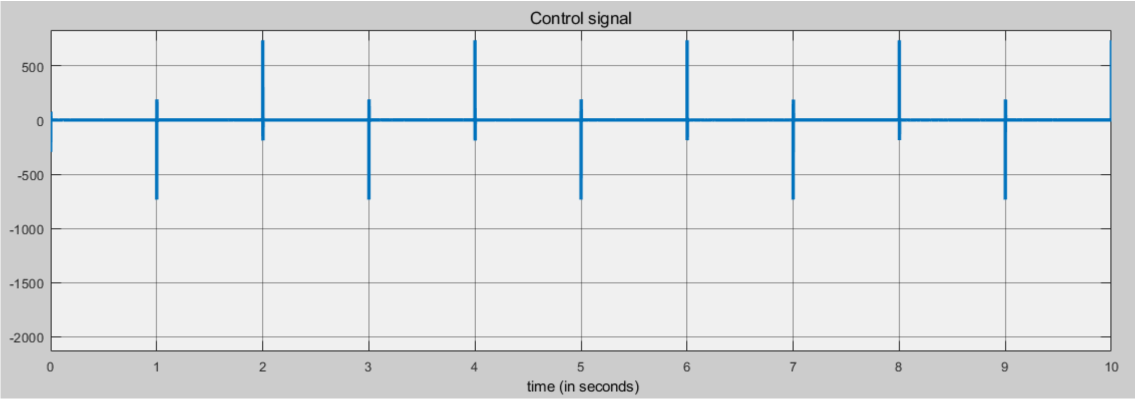

Figure 6.18 Control signal for square input (PIDD2)

CHAPTER 7

CONCLUSION AND FUTURE SCOPE

After dynamic model analysis of maglev system, the transfer function was developed which is further used for a simplified mathematical model.This linearized mathematical model is used as the plant function in in cascade with controllers with a negative feedback in the path to improve stability.

With the application of various controllers, it is found that with the additions of more gain values and blocks, a better transient response and stability are observed. To check the efficacy of the applied controllers, three inputs have been applied. One is step input with an initial value of 0.009 and 0.0055 and other two are square and sine waves. A sine input with amplitude of 5 mm and square input with amplitude 5mm are provided and the response is observed.

With the implementation of PD controller in the feedback, we observe an improvement in transient response but a decent amount of SSE is observed. In this case, the best transient response is observed in case of HBA while the other three seems sluggish in response as compared to HBA. While the other parameters are comparable with each other with a large SSE of 16% per average.

With the introduction of PID controller in feedback, improvement in transient as well as steady state is observed. In this case, the best transient response is observed in case of GPC. In HBA, we observe a high overshoot but less steady state error with a less settling time while the other two (GA and PSO) seems sluggish in response as compared to HBA and GPC. Settling time (2.714s) and SSE of .58% is least for GPC while HBA results are comparable with 2.84s settling time and 1.08% SSE with that of GPC.

Finally, with the implementation of PIDD2 controller in feedback, a better transient response along with very less steady state error is observed as compared to PID controller. In this case, responses of PID obtained trajectory with HBA and GPC has been compared with PIDD2 controller applied with GPC algorithm. In this response, a better transient response is observed in PIDD2 controller with a rise time of .0099s and settling time of 1.94s and SSE of 0.66%, which is the minimum observed in all three controllers (PD, PID and PIDD2).

Different controllers have been applied to observe more closely followed trajectory of the reference signal. Various algorithms have been helpful in getting an almost following trajectory. Newly developed algorithms like GPC and HBA have proved to be useful in finding the gains of the controller for the best results.

With the result of highly intensive investigation, which has been carried out in this area, the following suggestions can be applied in future, which are worth to be pursued.

1. The controllers used like PD, PID and PIDD2 can be replaced with algorithms developed by machine learning like SOM.
2. EA-SOM is a recently developed algorithm inspired by Machine Learning.
3. In addition, ANN can be applied to develop a new controller with the use of high-level language like Python, which is very easy to understand.
4. The simulation results need to be verifiedR42824 with the real time results so the actual error and its implementation can be checked for efficacy.

REFERENCES

[1] P. Suster , A. Jadlovska, “Modeling and control design of magnetic levitation system”, IEEE 10th International Symposium on Applied Machine Intelligence and Informatics, 2012, pp. 295–299, 2012

[2] W. Jones, “Earnshaw„s theorem and the stability of matter”, Eur. J. Phys. 1, pp.85-88,1980, Printed in Northern Ireland

[3] Heller, A. “Maglev on the Development Track for Urban Transportation”, November, Lawrence Livermore National Laboratory, University of California for the U.S. Department of Energy, 2004

[4] Ahmed El Hajjaji and M Ouladsine, “Modeling and Nonlinear Control of Magnetic Levitation Systems”, IEEE Transactions on Industrial Electronics, vol. 48, No. 4, pp. 841-848, 2001.

[5] W. Barie and J. Chiasson, “Linear and nonlinear state-space controllers for magnetic levitation,” International Journal of System Science, Volume 27, Issue 11 November 1996, pp. 1154-1164.

[6] S. Yadav, S. K. Verma, and S. K. Nagar, “Optimized PID controller for magnetic levitation system,” IFAC-Papers On-Line, vol. 49, no. 1, 2016, pp. 778–782.

[7] Dan Cho, Yoshifumi Kato, and Darin spilman “Sliding mode and classical controllers in magnetic levitation systems” IEEE Control Systems, Vol. 14, no. 1, pp. 42-48, 1994.

[8] H. K. Chiang, C. C. Fang, W. B. Lin, and G. W. Chen, “Second-order sliding mode control for a magnetic levitation system,” the 8th Asian Control Conference (ASCC), 2011, pp. 602-607.

[9] S. S. Mishra, S. K. Mishra and S. K. Swain, "Coefficient diagram method (CDM) based PID controller design for magnetic levitation system with time delay", 2017 IEEE International Conference on Intelligent Techniques in Control, Optimization and Signal Processing (INCOS), Srivilliputhur, 2017, pp. 1-8.

[10] B. Tandon, S. Kaur and A. Kalra, "Stability analysis of feedback linearized magnetic levitation system using sum-of-squares method”, 2017 4th International Conference on Signal Processing, Computing and Control (ISPCC), Solan, pp. 420- 424, 2017.

[11] R. H. Subrata, J. L. Hardenberg and F. Gozali, "The use of pid controller to get the stable floating condition of the objects in magnetic levitation system”, 2017 15th International Conference on Quality in Research (QiR): International Symposium on Electrical and Computer Engineering, Nusa Dua, pp. 421-424, 2017

[12] A. S. C. Roong, C. Shin-Homg and M. A. B. Said, “Position control of a magnetic levitation system via a PI-PD control with feedforward compensation”, 2017 56th Annual Conference of the Society of Instrument and Control Engineers of Japan (SICE), Kanazawa, pp. 74-78, 2017

[13] R. E. Precup, C. A. Bojan-Dragos, E. L. Hedrea, M. D. Rarinca and E. M. Petriu, “Evolving fuzzy models for the position control of magnetic levitation systems”,2017 Evolving and Adaptive Intelligent Systems (EAIS), Ljubljana, pp. 1-6, 2017.

[14] B. Singh and V. Kumar, “A real time application of model reference adaptive PID controller for magnetic levitation system”, 2015 IEEE Power, Communication and Information Technology Conference (PCITC), Bhubaneswar, pp. 584-588, 2015.

[15] K. H. Su and C. Y. Li, “Supervisory fuzzy model control for magnetic levitation system”, 2016 IEEE International Conference on Networking, Sensing, and Control (ICNSC), Mexico City, pp.1-6, 2016.

[16] Ahmed El Hajjaji and M Ouladsine, "Modeling and Nonlinear Control of Magnetic Levitation Systems", IEEE Transactions on Industrial Electronics, vol. 48, No. 4, pp. 841-848, 2001.

[17] Kiyong Kim, Rao, P. and Burnworth, J., "Self-tuning of the PID controller for a Digital Excitation Control System," IEEE Transactions on Industry Applications, vol. 46, no. 4, pp. 1518- 1524, July-Aug 2010.

[18] Muhammad Shafiq and Sohail Akhtar, "Inverse Model Based Adaptive Control of Magnetic Levitation System", 5th Asian Control Conference, vol. 4, pp. 1414-1418, July 2004.

[19] C. Wu and C. Zhu, "Implicit generalized predictive control of an active magnetic bearing system," in Proc. IEEE 17th International Conference on Electrical Machines and Systems, Hangzhou, China, pp. 2419 – 2424, 2014.

[20] S. Sgaverdea, C. A. Bojan-Dragos, R. E. Precup, S. Preitl and A.Stinean, "Model predictive controllers for magnetic levitation systems", 2015 IEEE 10th Jubilee International Symposium on Applied Computational Intelligence and Informatics, Timisoara, pp. 171-176, 2015.

[21] M. Ahsan, N. Masood and F. Wali, "Control of a magnetic levitation system using non-linear robust design tools", 2014 4rd IEEE International Conference on Computer, Control and Communication (IC4), Karachi, pp. 1-6, 2014.

[22] A. Rawat and M. J. Nigam, "Comparison between adaptive linear controller and radial basis function neurocontroller with real time implementation on magnetic levitation system", 2014 IEEE International Conference on Computational Intelligence and Computing Research, Enathi, pp. 1-4, 2014.

[23] I. Mizumoto and A. Minami, "Anti-windup adaptive PID control for a magnetic levitation system with a PFC based on time-varying ASPR model", 2011 IEEE International Conference on Control Applications (CCA), Denver, CO, pp. 114-118, 2011.

[24] C. S. Chin, C. Wheeler, S. L. Quah and T. Y. Low, "Design, modeling and experimental testing of magnetic levitation system for conveyance applications", 2011 IEEE 2nd International Conference on Computing, Control and Industrial Engineering, Wuhan, pp. 174-179, 2011.

[25] C. S. Teodorescu, N. Sakamoto and S. Olaru, "Controller design for sine wave tracking on magnetic levitation system: A comparative simulation study", 2010 IEEE International Conference on Control Applications, Yokohama, pp. 2241-2246, 2010.

[26] J. H. Yang, Y. S. Lee and O. K. Kwon, "Development of magnetic force modeling equipment for magnetic levitation system", ICCAS 2010, Gyeonggi-do, pp. 29-44, 2010.

[27] A. C. Unni, A. S. Junghare, V. Mohan, and W. Ongsakul, "PID, Fuzzy and LQR controllers for magnetic levitation system," the International Conference on Cogeneration, Small Power Plants and District Energy (ICUE), 2016, pp. 1-5.

[28] S. Yadav, S. K. Verma, and S. K. Nagar, "Optimized PID controller for magnetic levitation system," IFAC-Papers On-Line, vol. 49, no. 1, 2016, pp. 778–782.

[29] S. Yadav, S. K. Verma, and S. K. Nagar, "Performance enhancement of magnetic levitation system using teaching learning based optimization," Alexandria Engineering Journal, vol. 57, no. 4, 2018, pp. 2427–2444.

[30] K. Anurag, and S. Kamlu, "Design of LQR-PID controller for linearized magnetic levitation system," the 2nd International Conference on Inventive Systems and Control (ICISC), 2018, pp. 444-447.

[31] D. Khimani, S. Karnik, and M. Patil, "Implementation of high-performance nonlinear feedback control on magnetic levitation system," IFAC-PapersOnLine, vol. 51, no. 1, 2018, pp. 14–18.

[32] A. C. Unni, A. S. Junghare, V. Mohan, and W. Ongsakul, “PID, Fuzzy and LQR controllers for magnetic levitation system,” the International Conference on Cogeneration, Small Power Plants and District Energy (ICUE), 2016, pp. 1-5.

[33] R. J. Wai, J. D. Lee and K. L. Chuang, “Real-Time PID control strategy for maglev transportation system via particle swarm optimization,” IEEE Transactions on Industrial Electronics, vol. 58, no. 2, Feb. 2011, pp. 629-646.

[34] A. H. ElSinawi and S. Emam, “Dual LQG-PID control of a highly nonlinear magnetic levitation system,” Fourth International Conference on Modeling, Simulation and Applied Optimization, Kuala Lumpur, Malaysia, 2011, pp. 1-4.

[35] Q. Chen, Y. Tan, J. Li and I. Mareels, “Decentralized PID control design for magnetic levitation systems using extremum seeking,” IEEE Access, vol. 6, 2018, pp. 4059-4067.

[36] D. G. Padhan and S. K. Tummala, “Control of a magnetic levitation system using cuckoo search PIλDμ controller,” 15th IEEE India Council International Conference (INDICON), 2018, pp. 1-5.

[37] S. M. R Rasid, Md. B. Hossain, Md. E. Hoque, Md. A. Azam And Md. S. Ali Sarder, “Modeling and control of a magnetic levitation system using an analog controller,” Acta Electronica Malaysia, , Zibeline International Publishing, vol. 4(2), 2019, pp. 41-44.

[38] Fanqi Bu and Jie Xu, “Predictive fuzzy control using particle swarm optimization for magnetic levitation system,” The proceedings of the 16th Annual Conference of China Electrotechnical Society. Lecture Notes in Electrical Engineering, vol. 889, 2022, pp. 1454-1469.

[39] Y. Sun, J. Xu, C. Chen and W. Hu, “Reinforcement learning-based optimal tracking control for levitation system of maglev vehicle with input time delay,” IEEE Transactions on Instrumentation and Measurement, vol. 71, 2022, pp. 1-14.

[40] Chao-Lin Kuo, Tzuu-Hseng S. Li and Nai Ren Guo, “Design of a novel fuzzy sliding-mode control for magnetic ball levitation system,” Journal of Intelligent and Robotic Systems 42, 2005, pp. 295–416.

[41] A. Fatemimoghadam, H. Toshani, M. Manthouri, “Control of magnetic levitation system using recurrent neural network-based adaptive optimal backstepping strategy,” Transactions of the Institute of Measurement and Control 42(14), 2020, pp. 2482-2495.

[42] S. Ekinci, D. Izci, & M. Kayri, “An effective controller design approach for magnetic levitation system using novel improved manta ray foraging optimization”. Arab J Sci Eng 47, 2022, pp. 9674–9694.

[43] Feedback Instruments Ltd., “Magnetic Levitation Installation & Commissioning 44-942IC”.

[44] Feedback Instruments Ltd. User Manual, “Magnetic Levitation Control Experiments Manual 44-942IC”.

[45] https://www.controleng.com/articles/feedback-controllers-do-their-best

[46] https://electronicscoach.com/proportional-derivative-controller.html

[47] https://electronicscoach.com/proportional-integral-derivative-controller.html

[48] D. Izci, S. Ekinci, E. Eker and A. Dündar, "Assessment of Slime Mould Algorithm Based Real PID Plus Second-order Derivative Controller for Magnetic Levitation System," 2021 5th International Symposium on Multidisciplinary Studies and Innovative Technologies (ISMSIT), Ankara, Turkey, 2021, pp. 6-10.

[49] https://in.mathworks.com/help/gads/genetic-algorithm.html

[50] Kennedy J. and Eberhart R. C. Particle swarm optimization. In Proceedings of the International Conference on Neural Networks; Institute of Electrical and Electronics Engineers. Vol. 4. 1995. pp. 1942–1948.

[51] Eberhart R. C. and Shi Y. Comparing inertia weights and constriction factors in particle swarm optimization. In Proceedings of the 2000 Congress on Evolutionary Computation (CEC '00). Vol. 1. 2000. pp. 84–88.

[52] Shi Y. and Eberhart R. A modified particle swarm optimizer. In Proceedings of the IEEE International Conferences on Evolutionary Computation, 1998. pp. 69–74.

[53] Harifi, S., Mohammadzadeh, J., Khalilian, M. et al. Giza Pyramids Construction: an ancient-inspired metaheuristic algorithm for optimization. Evol. Intel. 14, 1744–1761 (2021).

[54] F. A. Hashim, E. H. Houssein, K. Hussain, M. S. Mabrouk, W. Al-Atabany, "Honey Badger Algorithm: New metaheuristic algorithm for solving optimization problems," Mathematics and Computers in Simulation," Volume 192, 2022, pp. 84-110

LIST OF PUBLICATIONS

[1] V. Sharma, R. Bhagat and N. Kumar, "Pid Controller Tuning In Magnetic Levitation System Using Giza Pyramid Algorithm," *2023 International Conference on Power, Instrumentation, Energy and Control (PIECON)*, Aligarh, India, 2023, pp. 1-5, doi: 10.1109/PIECON56912.2023.10085826.

[2] V. Sharma, N. Kumar and R. Bhagat, " TUNING OF PID CONTROLLER IN MAGNETIC LEVITATION SYSTEM APPLYING HONEY BADGER ALGORITHM," *7th International Conference on Emerging Trends in Engineering, Science and Technology ICETEST 2023*, Thrissur, India, 2023.