Shradha Kishore, et. al. International Journal of Engineering Research and Applications
www.ijera.com
ISSN: 2248-9622, Vol. 10, Issue 6, (Series-IV) June 2020, pp. 01-09

RESEARCH ARTICLE OPEN ACCESS

Performance comparison of PID and TID controllers using Genetic Algorithm and Grey Wolf Optimization technique for Magnetic levitation system

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ABSTRACT
This paper is about the performance comparison of controller for magnetic levitation system. In this study, Tilt Integral Derivative (TID) controller and Proportional Integral Derivative (PID) controller have been designed for a Magnetic Levitation (Maglev) system and the controller parameters have been optimized using Genetic Algorithm (GA) and Grey Wolf Optimization (GWO) technique. A performance comparison is also done for the two optimization techniques.A performance comparison of the two methods clearly indicate that Grey Wolf Optimization is a better method among the two for tuning of PID and TID Controllers.
In future there is a need for some kind of model evaluation. An extensive work on variable mass model evaluation is needed to solve the uncertainties that arise in the evaluation of controller parameters.
***Keywords*- Controller, Optimization, Genetic algorithm(GA), Grey Wolf Optimization(GWO), PID, TID.**

Date of Submission: 26-05-2020 Date of Acceptance: 11-06-2020

I. INTRODUCTION

Magnetic levitation systems are nonlinear and unstable. As a result of this the researchers have found it very difficult to control this system. Over a period of time they have tried to control it both through hardware control and software programs.

This paper is about theperformance comparison of TID and PID controllers for maglev system. In this study two optimization techniques- The Genetic Algorithm and Grey Wolf Optimization have been applied to optimize the parameters of TID controller and the values obtained are used in the designing of controllers. A Simulink model has been designed to simulate the behavior of both controllers for these optimized values.

The comparative study has been done using the real time responses, the result clearly indicate that TID controller can be used for application in other plants**.**A performance comparison of the two methods clearly indicate that the response using GreyWolf Optimization has less peak overshoot, rise time and settling time. Thus the Grey Wolf Optimization is a better method for tuning of both the controllers.

II. MAGNETIC LEVITATION SYSTEM

Magnetic Levitation systems are electromechanical systems that are used to levitate objects in space without any support [1]. They are examples of open loop unstable system with fast dynamics [2].Magnetic levitation systems are becoming more and more popular over the years especially in Maglev Trains. Also many motors in which the rotating shaft is levitated using a magnetic flux is being used commercially in bearing lessmotors, magnetic levitation vehicles and wind turbines [3]. The maglev systems have the advantage that they reduce friction and are less expensive to operate and maintain.

Our Maglev setup consists of a mechanical unit on which coil is mounted. An infrared sensor is attached to the unit. a steel ball is levitated using a magnetic field. The position of the ball is sensed by an IR sensor which sends signal to the Analog to digital converter which generates a PWM drive signal accordingly.

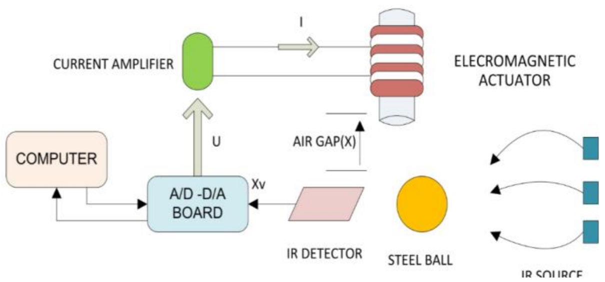

Fig1. Schematic diagram of the Maglev System

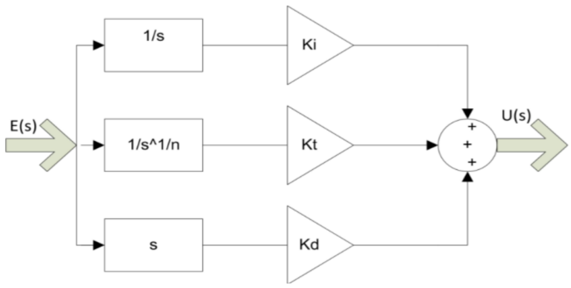

Fig 2. Schematic diagram of the Maglev System

III. THE CONTROLLER

The PID controller was first developed by Elmer Sperry in 1911. The PID Controllers are the most widely used controllers in the industry [3]. Their stability analysis is extremely easily to carry out and they can be tuned easily. PID control uses a closed loop control feedback to keep the actual output as close to the set point as possible.The overall transfer function of the controller is given by G(s) = Kp*s+Ki*(1/s) +s*Kd.Selection of values of PID control has significant effect on control performance [5-6].

The fractional order calculus is very important for the design of controller nowadays. The concept of fractional order controller was first proposed by Podlubny in 1999 [7].Like the PID Controllers the fractional order controllers also involve tuning of its parameters so as to meet the desired specifications. The classical PID controller is considered as a special case of fractional order controllers. A novel method for tuning FOPID parameter is minimizing integral absolute error which is being used nowadays. The fractional order controller provides more flexibility and opportunity to adjust the dynamic properties of control system. They also exhibit good robustness.

It consists of three tunable components in a feedback loop which has a PID compensator. The term 'Tilt' means that it can provide a feedback gain which is tilted with respect to gain frequency of the conventional compensation unit. It is similar to a PID controller except the fact that instead of a proportional unit a compensator which has the transfer function represented by $Kt/s^{1/n}$is present. The overall transfer function of the controller is given by $G(s) = Kt*s^{1/n}+Ki*1/s +s*Kd$, where 'n' is a non-zero number. The value for 'n' lies between 2 and 3. In this paper the value of 'n' is chosen to be 2. The mathematical model of the controller is shown below: -

The effects of the controller can be summarized as below: -

- It is simple to tune.
- The ratio of disturbance to rejection is improved.
- Feedback control is improved.
- The closed loop is less sensitive to parameter variations of the plant.

IV. DOMINANT POLE APPROXIMATION

The design specifications for this study have been considered as: -
Settling time ≤ 2 sec and damping ratio (ζ) ≤ 0.8
The dominant poles were calculated to be at $S_{1,2}= -2\pm 1.5i$ [8-9]

V. SYSTEM WITH TID CONTROLLER

The characteristic equation for the closed loop negative unity feedback system is given by

$$1+Gp(s)*Gc(s)=0 \qquad (1)$$

$$\text{i.e. } 1+\left(\frac{-3653.3575}{S^2-2180}\right) * \left(\frac{k_t}{S_n^{\frac{1}{}}}+\frac{k_I}{s}+sk_d\right) = 0 \quad (2)$$

VI. OPTIMIZATION

Optimization is the process of finding best solution from all possible solutions. Traditional methods based on gradients like Newton's Method and dynamic programming have been used to find minima and maxima for differential equations [10]. These methods have a disadvantage that they are not applicable in case of unstable, discontinuous or complex systems. Also they are more likely to get trapped at saddle points and give incorrect results. Due this limitations nontraditional methods were developed over the course of time drawing inspiration from Darwin's theory of natural selection, food searching ability of species and swarm behavior.

VII. OBJECTIVE FUNCTION

The integral absolute error has been taken as the objective function. The step response has been taken from equation (2). The result of it has been subtracted from equation(1) to find error. The modulus of step response of error has been optimized using Genetic Algorithm with the help of MATLAB code.

VIII. THE GENETIC ALGORITHM

Genetic algorithm is a search based optimization tool. It is inspired by Charles Darwin's theory of natural evolution. It was first described by John Holland in 1975 and popularized by David Goldberg [11].In this algorithm the fittest individuals are selected by the process of natural selection and they produce offspring for the next generation.

The process starts with the selection of fittest individuals from a population of defined size. A fitness function determines how fit an individual is as compared to others. Then they produce offspring's having characteristics of their parents. This process keeps on iterating until a generation with the fittest individual is found. This method is applied for a search problem where we consider a range of solutions for the problem and select the best ones out of them. The following flow chart shows the steps that are followed while optimizing the parameters using genetic algorithm.The below given steps are followed to produce an individual in a new generation which are better than the previous generation.

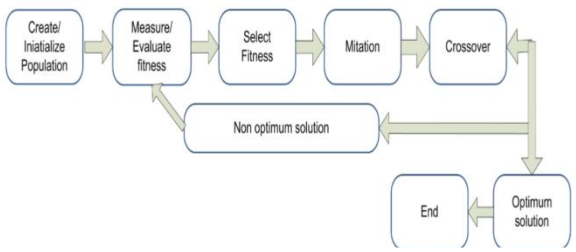

Fig3. Flow chart of Genetic algorithm

IX. THE OBJECTIVE FUNCTION OPTIMIZATION USING GENETIC ALGORITHM

The Integral Absolute Error has been taken as the objective function containing three unknown variables Kt, Ki and Kd for TID Controller. The population size, mutation probability, crossover probability and number of iterations are taken as 40, 0.125, 0.8 and 25 respectively. The range of controller parameters are taken as:

$-25 \leq Kt \leq -23$, $-6 \leq Ki \leq -4$ and $-0.25 \leq Kd \leq 0$

The decision has been taken after running the algorithm for a number of trials. The final parameters of the fine is run for 15 times to get the final optimum value of the controller parameters. The values obtained after the optimization are: -

Kt= -24.5293, Ki= -5.9815 and Kd= -0.0846

These values are used for designing of TID controllers.

The range of controller parameters for PID are taken as:

$-50 \leq Kp \leq 0$, $-50 \leq Ki \leq 0$ and $-50 \leq Kd \leq 0$

The values obtained after the optimization are: -

Kp= -29.492, Ki= -49.997 and Kd= -2.642

X. GREY WOLF OPTIMIZATION TECHNIQUE

The grey wolf optimization is a swarm intelligent optimization algorithm developed by Seyedali Mirjalili et al. in 2014 [11]. It imitates the leadership hierarchy of the wolves which are well known for their group hunting. The wolves are divided into four types of wolf: alpha, beta, delta and omega, where the best individual, second best individual and third best individual are termed as alpha, beta, and delta, and the rest of the individuals are considered as omega. The wolf as top predators in the food chain, has a strong domination [12-15].

The leader of all the groups is Alpha type which is the decision maker among all the groups other group takes feedback from all other group of lower hierarchy (i.e. beta, delta and omega) in the process like searching encircling and hunting the prey. They are the fittest individuals among all the groups.

Level 2 is the beta, they are subordinate Wolves, and advisor to the alpha, beta ensures that all the subordinate should obey the order.

Level 3 are called delta.They dominate omega and report to alpha and beta. They are responsible for watching the boundaries, protecting the pack and help alpha and beta in hunting and care for ill and wounded wolves.

Level 4 groupis Omega which are used for searching the pray and they are allowed to eat the prey at the last.They have lowest fitness value.

10.1. SEARCH PROCESS

The search process is the modeled behavior of the wolves which wolves use in their haunting process, there are mainly three stages like searching, encircling and attacking the prey.The first two stages are dedicated to exploration and the last one is the exploitation. First they explore the prey and encircle them and they create the situation to attack on the prey position. The fittest in the group change their position to search the best position for haunting and the move towards the goal (i.e. prey position) and update their position continuously after each change to get to the optimal position to attack. The similar concept is used in the grey wolf optimization. Alpha, beta, delta and omega search for the position of the goal, encircle the goal by different search agents and move forward till the optimal goal position is not reached. The alpha is followed by all others of lower hierarchy.

This algorithm has been developed to solve a complex problem very efficiently and fast. In grey wolf optimization first three best solutions are updated and saved which are in the form of alpha, beta and delta. And the rest the left search agents are compelled to update their position according to the position of best search agents. Grey wolves search to the position of the alpha, beta, and delta, they diverge from each other to search and converge to attack the prey, the decision for the diverge and converge form the prey is based on the coefficient 'A' which has been defined mathematically.

In optimization process, the locations of wolves are updated based on Equations (3) and (4)

$$\vec{D} = \left|\vec{C}\vec{X}(t) - \vec{X}(t)\right| (3)$$

$$\vec{X}(t+1) = \vec{X_P}(t) - \vec{A}.\vec{D} (4)$$

Where t indicates the current iteration, $\vec{A}$ and $\vec{C}$ are coefficients vectors, $\vec{X_P}$ is the position vector of the prey, and $\vec{X}$ indicates the position vector of the grey wolf.

Hence, after the exploration if the prey is found, they encircle the prey. For encircling in space search the position has to be changed, so in this algorithm, the mathematical equation (4) and (5) has been defined to get the position vector of the search agents after each change.

$$\vec{A} = 2\vec{a}.\vec{r_1} - \vec{a} (5)$$

$$\vec{C} = 2.\vec{r_2} \ (6)$$

$$a = 2 - \frac{t}{\max\ iteration} \quad (7)$$

$$\vec{D_\Delta} = |\vec{C_3}\vec{X}_\Delta - \vec{X}|$$

$$\vec{X}_1 = \vec{X}_\alpha - \vec{A}_1\vec{D}_\alpha \ (9)$$

$$\vec{X}_2 = \vec{X}_\beta - \vec{A}_2\vec{D}_\beta$$

$$\vec{X}_3 = \vec{X}_\alpha - \vec{A}_3\vec{D}_\Delta$$

When the vector $|A| < 1$ during the course of iteration, the wolves attack the pray reaching to the best optimum value.

10.2.THE ALGORITHM

The total search agents present in the search space; the fitness value is calculated using the predefined objective function for each search agents. And based on that fitness value the best 3 solutions are be shortlisted, after that based on

Where $\vec{r_1}$ and $\vec{r_2}$ are random vectors in [0,1] and component 'a' is linearly decreasing from 2 to 0 with the increase in the iteration to reduce the gap between the position and the prey. The vector A and C are calculated for each iterations and vector D is calculated and position $\vec{X}(t+1)$ are updated for each iterations for every wolves(alpha, beta , delta and omega) .The position vectors of search space can be considered in 2D and 3D space and can be defined accordingly.

The hunt is usually guided by alpha. The beta and delta might also participate in hunting, in case of abstract search space there is no idea about the optimum location, for that we consider that alpha in the search space which gives the best solution and beta and delta have better knowledge about the location of the prey. The first three best solutions are stored in the form of alpha, beta and delta and other search agents are compelled to update their position according to the best search agents (i, e. beta, delta and omega).

The formulas shown in the equation no. (3) and (4) are used for saving the updated positions for each wolves $X_\alpha, X_\beta, X_\Delta$ after each iteration and the mean position is calculated as shown in equation no. (7),(8),(9). The other left search agents will try update to this mean position. The mathematical model for hunting behavior is as follows:

$$\vec{X}(t+1)(\text{mean}) = \frac{\vec{X}_1 + \vec{X}_2 + \vec{X}_3}{3} \ (7)$$

$$\vec{D_\alpha} = |\vec{C_1}\vec{X}_\alpha - \vec{X}| \ (8)$$

$$\vec{D_\beta} = |\vec{C_2}\vec{X}_\beta - \vec{X}|$$

these 3 best solution the position of other search agents is updated and again 3 best solutions are achieved and this process will carry on till the iteration terminates. Algorithms associated with grey wolf optimizer:

- Initialize the grey wolf population size n parameter a, coefficient vectors A, C and the maximum no. of iteration.
- Set t=0 as the counter initialization.
- For (i=1: i≤ n)
- Generate the initial population $X_i(t)$ randomly.
- Evaluate the fitness function of each search agents by calling the objective function in the main function (f($X_i(t)$) .
- End for.

- Assign the values to the first, second and the third best solution X_α, X_β and X_Δ respectively.
- Repeat
- For (i=1: i ≤ n) do
- Update each search agents in the population as discussed using above equation (7), (8) and (9).
- Decrease the parameter 'a' from 2 to 0.
- Update the coefficients A and C as shown in equation (5) and (6).
- Evaluate the fitness function of each search agent f($X_i(t)$).
- End for
- Update the vectors $X_\alpha, X_\beta, X_\Delta$.
- Set t=t+1
- Until t < Maximum iteration (till Termination criteria is satisfied).
- Produce the best solution X_α.

XI. RESPONSES AND RESULT

The tuning of TID and PID controllers by using grey wolf optimization(GWO) technique and the Genetic algorithm (GA) have been used. ForGWO,the number of search agents

is chosen as 30 and the number of iteration as 125.The algorithm was run a number of times and the values of controller's parameters are selected based on the values returned by alpha wolf in the algorithm, which was the fittest among all other wolfs. For tuning of the controller the objective function has been calculated i.e., the error function so as to get the minimized integral absolute error (IAE) of the response. Once the objective function is decided, this function has been called to the part where the GWO algorithm is written, and the program is run for maximum no. of iteration that has been assigned. The algorithm returns the value of the position of the fittest group (alpha group), which is analogous to the value of the controller parameter that is Kp, Ki, Kd for PID and Kt, Ki, Kd for TID controller.

The objective function is the overall transfer function of the controller containing three unknown variables Kt, Ki, Kid, has been optimized through Genetic algorithm(GA)with fixed number of iterations, population size,crossover probability, bit size, and mutation probability taken as 25, 40,0.8 ,10, and 0.125 respectively.The decision regarding the boundary limits of these unknown parameters has been made after performing a number of trial runs, and the optimization has been done on the GA tuning app of the MATLAB software.

After optimization, the values obtained for GWO and GA for both TID and PID controller is shown in table 1, and 2 respectively. These values are then used for designing the both TID and PID controller and obtaining controlled response of nonlinear, unstable magnetic levitation system.

Table 1. Optimized TID controller parameters obtained by GWO and GAandthe time domain specification for the step response of the overalltransfer function.

Optimization technique	Iteration	Value of Integral absolute error (IAE)	Kt	Ki	Kd	Rise time(s)	Settling time(s)	Overshoot
GWO	125	0.0252	-21.11	-10	-10.21	0.7957	8.2251	2.7931
GA	125	0.0396	-24.952	-5.981	-0.0846	0.7517	3.1795	6.4194

The step responses of the overall system obtained by using the optimized values obtained for GA and GWO for TID and PID controllers are as show in Fig. 4, 5, 6 and 7 respectively.

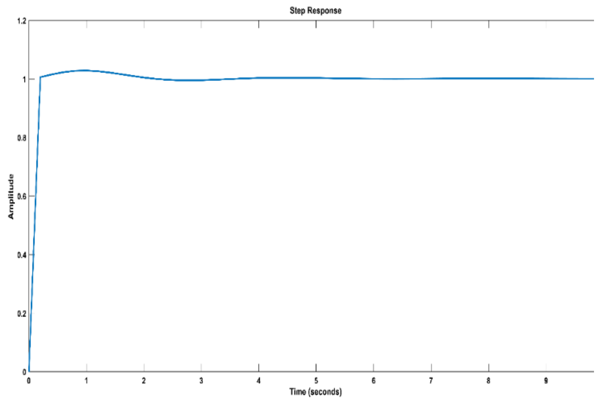

Fig 4. Step response of the overall system using TID controller for GWO

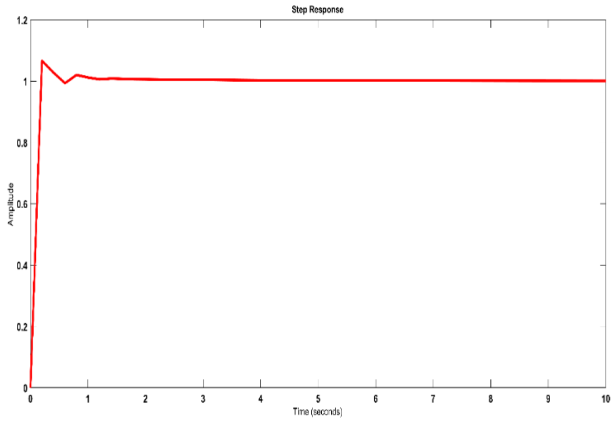

Fig 5. Step response of the overall system using TID controller for GA

Table 2. Optimized PID controller parameters obtained by GWOand GA andthe time domain specification for the step response of the overalltransfer function.

Optimization technique	Iteration	Value of Integral absolute error (IAE)	Kp	Ki	Kd	Rise time(s)	Settling time(s)	Overshoot
GWO	125	0.0102	-14	-19.5	-0.8	0.00738	0.00125	0.605
GA	125	0.044	-29.49	-49.7	-2.64	0.00227	0.00401	0

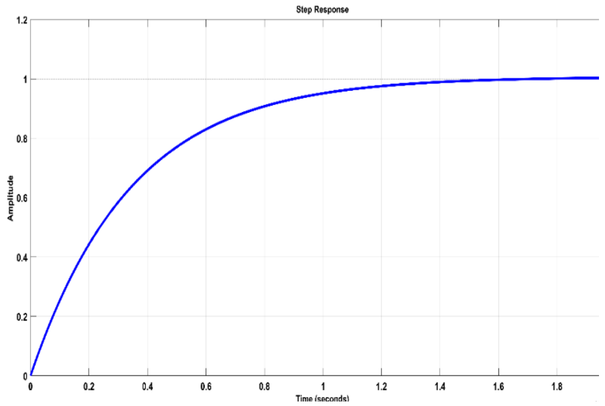

Fig 6. Step response of the overall system using PID controller for GWO

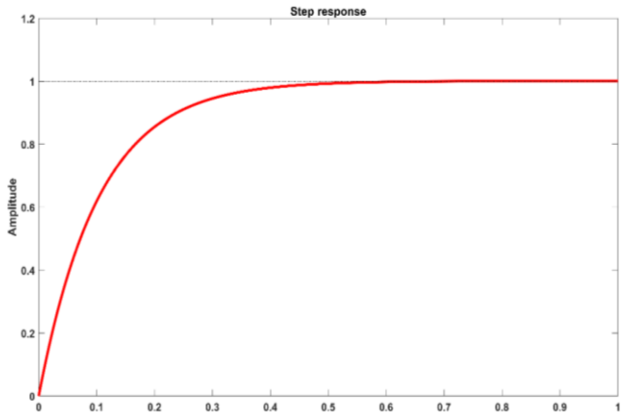

Fig 7. Step response of the overall system using PID controller for GA

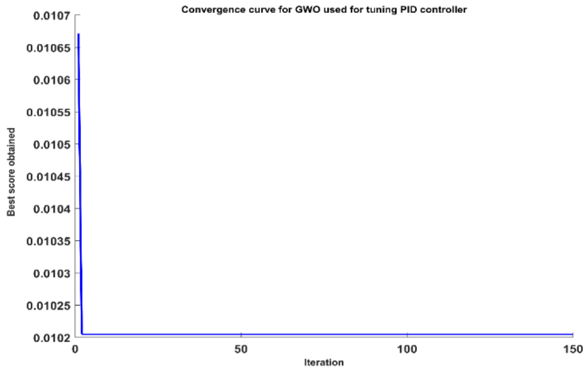

Fig 8. convergence curve using GWO for PID controller

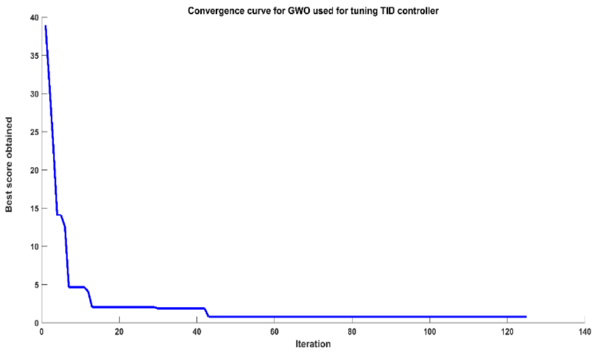

Fig 9. convergence curve using GWO for TID controller

The output of the controller(volts) is obtained indicating the controller action for every step change of the reference signals(input voltage) as shown in Fig.10,11,12 and 13.For every step change of the input signal the ball under levitated system is getting a sharp change in the position which is sensed by the sensor which has some specific gain (distance to voltage gain) .The value is returned by the sensor and compared with the input(reference voltage) voltage (negative feedback system) and the error signal corresponding to the displaced position of the ball from the equilibrium position is made as input of the controller. The value of controller gain has been set using the optimization techniques and the control action take place based on the error input, till the ball comes at set equilibrium position.

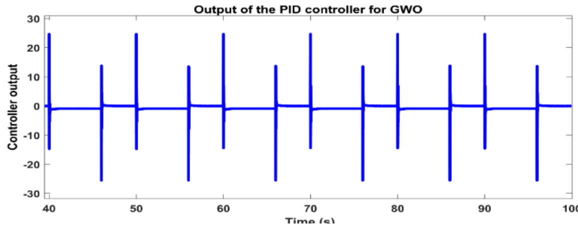

Fig 10. Output of the PID controller for GWO

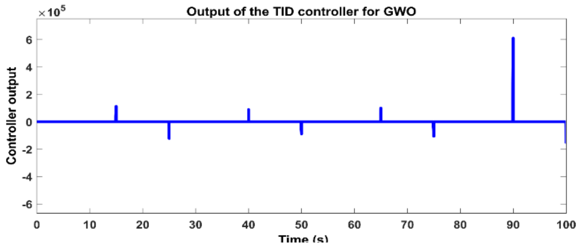

Fig 11. Output of the TID controller for GWO

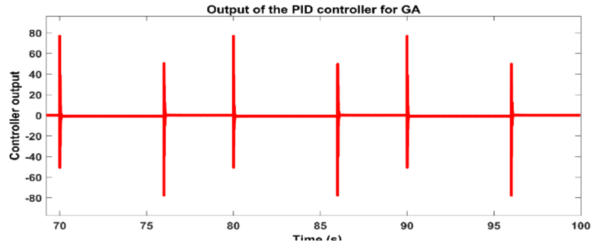

Fig 12. Output of the PID controller for GA

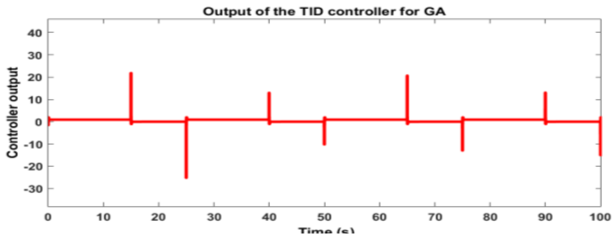

Fig 13. Output of the TID controller for GA

The simulation response for TID and PID controller action has been shown in Fig.14 and Fig.15. The value of the controller parameters obtained using GWO and GA has been used in the simulation for TID and PID controller action to lift the ball in magnetic levitation system without any unstable transient response. The response clearly depicts that the comparative study has been done for same controller using different optimization technique. The response shown in the figure no. 14 shows larger overshoot, when tuned controller parametersusing GA tuningare used,and that with GWO has relatively less overshoot.

The similar response for the controller gains for TID controller set by using GA in Fig.13 which indicates the sharp rise in the ball position with more oscillations is the transient part with more settling time, for the GWO tuning the response has less overshoot and soft control by the controller with relatively less settling time.

The sharp transition at the step change of the input signal, this may lead to the dropping of the ball out of the levitation, which may result into system failure. If the ball continues to levitate and transients settle down, then the system can be considered to be robust under such settings of the controller.

The IAE is also minimum for tuning using GWO as compare to GA as tabulated above, the values of absolute error show the sensitivity of the system to variations in the parameters.so the parameters used from the optimization using GWO makes the controller less sensitive to the external variations thus making the system more robust.

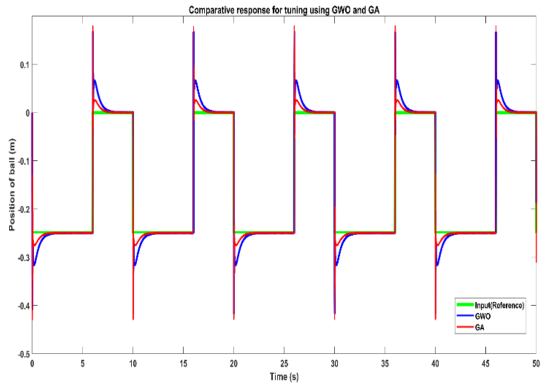

Fig 14. Comparative response for GA,GWO for PID controller

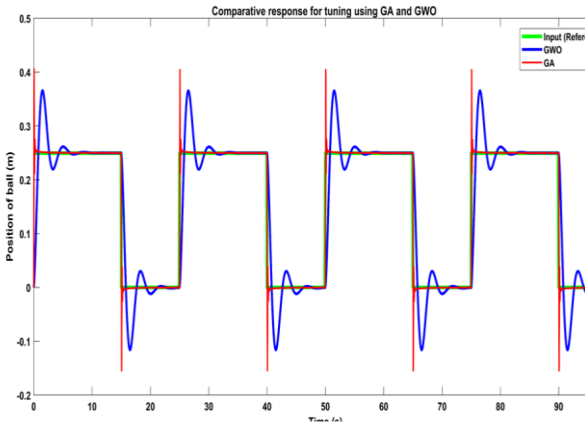

Fig 15. Comparative response for GA, GWO for TID controller

XII. SIMULATIONS

The simulations of the TID and PID controller has been done to obtained the response of the ball for the comparative study of the response of the plant using optimized controller parameter obtained from GWO and GA. The input signal (voltage) with average value of -1.55 volts and the Pre-filter has been used to reduce the steepness of the signal at step change. The voltage to position converter has been used to obtain the response of the ball with the equilibrium point(reference) and to maintain the analogy with voltage and position with in simulation. The value of voltage to position converter is chosen as 0.161(m/voltage) which gives the position of the ball for the corresponding voltage supplied.

The TID controller has been designed using fractional integrator block (nid bock) obtained from the FOMCON Simulink toolbox of the MATLAB software. The plant transfer block is cascaded with the controller output. Similarly, for simulation of magnetic levitation system using PID controller, the nid block have been removed as it was in TID. Instead of signal builder block the square wave pulse generator block have been used in the simulations.

XIII. CONCLUSION

In this study TID and PID controllers have been designed for nonlinear Magnetic levitation system and the simulated responses are compared. Optimization techniques, Grey wolf optimization(GWO) and Genetic algorithm(GA) have been used to find the optimized value of the controller parameters the and to minimize the integral error of the system.From the above findings it is clear that response of the system for GWO has the potential to provide better transient response and relative stability as compare to traditional GA optimized controller transfer function. The simulation using both the controllers have been done in MATLAB with proper plant transfer function. These controller parameters obtained from optimization are hence used for the Simulated responses, step response information such as rise time, settling time, peak time and overshoot are gathered. The comparative study has been done using the responses, the result clearly indicates that TID and PID controller can be used for application in other plants with optimization technique as GWO which gives more suitable controller parameters for more robust controlling.
Further in future other traditional optimization techniques can be incorporated with different type controller configurations with better choice of the controller parameters with improved version of levitation technology.

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Shradha Kishore, et. al. "Performance comparison of PID and TID controllers using Genetic Algorithm and Grey Wolf Optimization technique for Magnetic levitation system." *International Journal of Engineering Research and Applications (IJERA*), vol.10 (06), 2020, pp 01-09.