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Tuning of PID Controller Using GA and PSO Optimization Technique and Compare with Integral Errors

Manish Rathore , Preeti Verma , Dr Rajeev Gupta

***Abstract*— The paper Present to design PID controller parameters for an under-actuated system using Particle Swarm optimization (PSO) and genetic algorithms (GA) . The design goal is to minimize the optimal parameters of the integral errors and reduce transient response by minimizing overshoot, settling time and rise time of step response. First an objective function is defined, and then by minimizing the objective functions using real-coded PSO and GA , the optimal controller parameters can be assigned. The maglev system taken for case study is inherently un-actuated system in the direction of levitation, and the relationships among air gap, current and electromagnetic force are highly nonlinear and after tuning of PID using PSO and GA, results stable with make Unit step system.**

***Index Terms*— Feedback System, GA, Magnetic levitation system, Optimization, PID**, PSO

I. Introduction

The magnetic levitation is a method which is used for suspending an object in the air, without any physical contact. There are few main types of the magnetic levitation electromagnetic, electrodynamics. Transformation, super conductive and diamagnetic. All these are usually based on the force interaction between magnetic field and gravitation field. The magnetic levitation is especially used in some hi-tech devices (e.g. Maglev trains, frictionless bearings etc).

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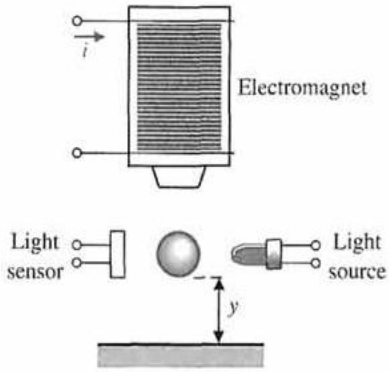
***Manish Rathore** is PG (M.TECH) Student of UCE, Rajasthan Technical University, KOTA, India Mob.No.9782159871;*
***Preeti Verma** is PG (M.TECH) Student of UCE, Rajasthan Technical University,KOTA,,India,Mob.No9602053437.;*
***Rajeev Gupta** is HOD & Prof. of EC Deptt. UCE, Rajasthan Technical University KOTA (Mob.No.9414596 958;*



The transformation levitation system is used for positioning of electrically conductive materials by electromagnetic forces. It is obvious a feedback control .Circuit is necessary to ensure a stable position of the levitating object. A control unit adjusts the current in the electromagnet. The position is tracked by a sensor; usually photo sensor. Hall Effect sensor etc. is used. According to the signal of the sensor the electromagnet is driven up or down. If the ferromagnetic object is above the desired position. the controller reduces the current in the electromagnet and the magnetic force as well. If the object is below the desired position, the current in the electromagnet increases. PID Controllers have been widely used for speed and position control of various applications. For a wide range of practical processes, this tuning approach works quite well. To enhance the capabilities of traditional PID parameter tuning techniques, several intelligent approaches have been suggested to improve the PID tuning, such as those using genetic algorithms (GA) and the particle swarm optimization (PSO). These parameters can be optimally obtained via Particle swarm Optimization (PSO) and Genetic Algorithm (GA). Particle swarm optimization (PSO) is a novel emerging intelligence which was flexible optimization algorithm. This project attempts to develop a PID tuning method using PSO algorithm. PSO algorithm is a stochastic algorithm based on principles of natural selection and search algorithm. There are many evidences of intelligence for the posed domains in animals, plants, and generally living systems.

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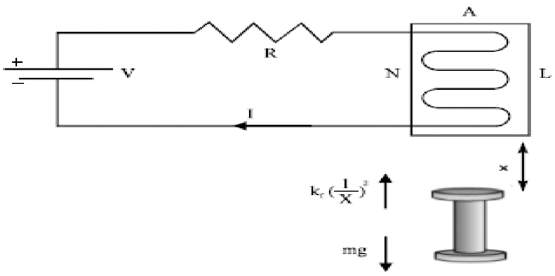
II. PROBLEM FORMULATION



Meglev System parameters:
Inductance L= .508 H
Resistance R= 23.2 ohm
Current is $i_1 = I_0 + i$
$I_0 = 1.06$ A is the operating point
I is variable
Mass m = 1.75 kg
the gap is $x_g = X_0 + x$
Where X_0 4.36 m is operating point
x is variable
Electromagnetic force $f = k(i_1/x_g)^2$
$k = 2.9*10^{-4}$ Nm^2/A^2
[*] This parameter has been taken by dorf and bishap . Page no. 207
Let us consider the state variable are
$x_1 = x$
$x_2 = dx / dt$
$x_3 = I$
Now we can apply the KVL theorem
$V = L\,(di/dt) + iR$
Now by using force balancing equation
$F = ma = m\,dx^2/dt^2$
$F = mg - k(i_1/x_g)^2$

$m\,dx^2/dt^2 = mg - k[I_0 + i/X_0 + x]^2$
$dx^2/dt^2 = g - k/m * [I_0 + i/X_0 + x]^2$
Taking variable: $x_1 = x$, $x_2 = dx/dt$, $x_3 = i$
Rewriting this equation

$$dx_2/dt = g - k/m *[I_0 + x_3/X_0 + x_1]^2 \quad \ldots\ldots 2$$

$$dx_1/dt = x_2 \quad \ldots\ldots 1$$

$$V = L\,(di/dt) + iR$$

$$dx_3/dt = (V - x_3 R)/L \quad \ldots\ldots 3$$

Solve the equation no. 2

$$dx_2/dt = g - k/m * [I_0 + x_3/X_0 + x_1]^2$$
$$= g - kI^2_0 /mx^2_0 *(1 + x_3 / I_0)^2 *(1 + x_1/x_0)^{-2}$$
$$= g - kI^2_0 /mx^2_0 *(1 + 2x_3 / I_0) *(1 + 2x_1/x_0) \quad \ldots\ldots 4$$

by using Taylor series expansion ,

$$= g - kI^2_0 /mx^2_0 *(1 - 2x_1/x_0 + 2x_3 / I_0)$$
$$= g - kI^2_0 /mx^2_0 + (2kI^2_0\ x_1 / mx^3_0) - (2kI_0\ x_3 / mx^2_0)$$

Equation in State Space Form:

$$A = \begin{bmatrix} 0 & 1 & 0 \\ 2kI0\text{^}2/mx0\text{^}3 & 0 & -2kI0/mx0\text{^}2 \\ 0 & 0 & -R/L \end{bmatrix}$$

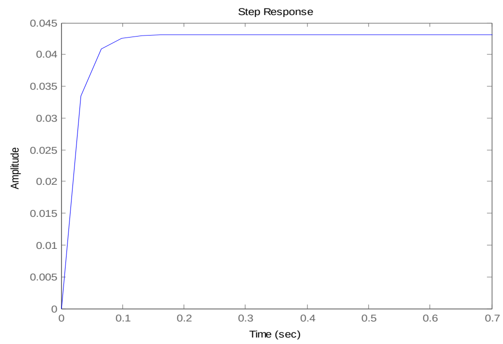
$$b = \begin{bmatrix} 0 \\ 0 \\ 1/L \end{bmatrix} \qquad C = \begin{bmatrix} 1 & 0 & 0 \end{bmatrix}$$

$$d = [0]$$

Transfer function of the system

```
1.969 s^2 - 1.076e-016 s - 0.06076
----------------------------------
s^3 + 45.67 s^2 - 0.03086 s - 1.41
```

STEP RESPONSE OF MAGLEV SYSTEM



THIS IS UNDER -ACUATED SYSTEM

III. PARTICLE SWARM OPTIMIZATION (PSO)

Particle swarm optimization (PSO) is an algorithm modeled on swarm intelligence, that finds a solution to an optimization problem in a search space, or model and predict
Social behavior in the presence of objectives. The PSO is a stochastic, population-based computer algorithm modeled on swarm intelligence. The approach is suitable for solving nonlinear problem. The approach is based on the swarm behavior such as birds finding food by flocking. A basic variant of the PSO algorithm works by having a population (called a swarm) of candidate solution (called particles). These particles are moved around in the search-space according to a few simple formulae. The movements of the particles are guided by their own best known position in the search-space as well as the entire swarm's best known position. When improved positions are being discovered these will then come to guide the movements of the swarm. The particle swarm simulates this kind of social optimization.

These individuals are candidate solutions. An iterative process to improve these candidate solutions is set in motion. The particles iteratively evaluate the fitness of the candidate solutions and remember the location where they had their best success. The individual's best solution is called the particle best or the local best

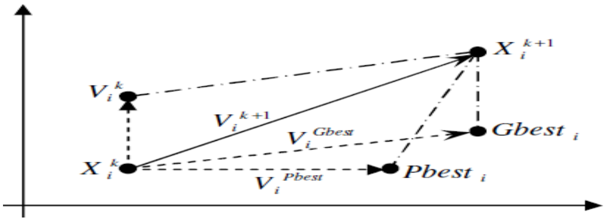
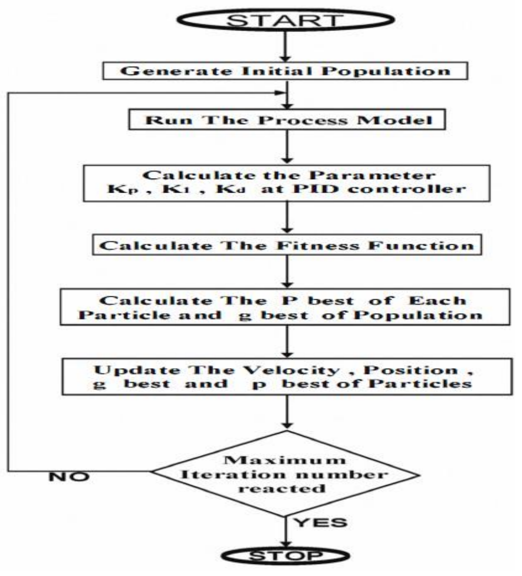


Fig. Concept of modification of a searching point by PSO

A. Implementation of PSO and GA -based PID tuning

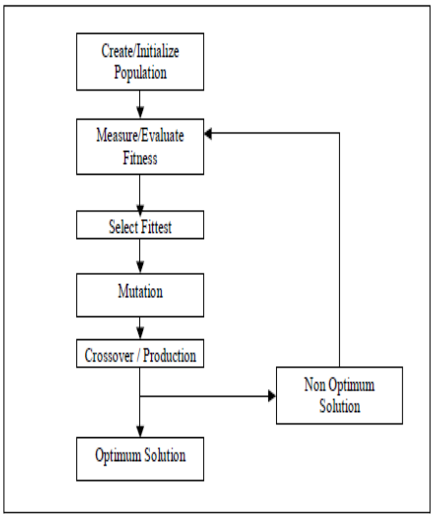
Stochastic Algorithm can be applied to the tuning of PID controller gains to ensure optimal control performance at nominal operating conditions. GA is employed to tune PID gains/parameters (Kp, Ki, Kd) in offline using the model in Eq. GA firstly produces initial swarm of particles in search space represented by matrix. Each GA represents a candidate solution for PID parameters where their values are set in the range of 0 to 100. For this 3-dimentional problem, position and velocity are represented by matrices with dimension of 3xSwarm size. The swarm size is the number of particle where 50 are considered a lot enough. A good set of PID controller parameters can yield a good system response and result in minimization of performance index.



IV. GENETIC ALGORITHMS (GA)

A **genetic algorithm (GA)**is a local search technique used to find approximate solutions to optimization and search problems. Genetic algorithms are a particular class of evolutionary algorithms that use techniques inspired by evolutionary biology such as *inheritance, mutation, selection, and crossover* (also called recombination).Genetic algorithms are typically implemented as a computer simulation, in which a population of abstract representations (called *chromosomes*) of candidate solutions (called individuals) to an optimization problem evolves toward better solutions. The evolution starts from a population of completely random individuals and occurs in generations.

In each generation, the fitness of the whole population is evaluated, multiple individuals are stochastically selected from the current population (based on their fitness), and modified (mutated or recombined) to form a new population. The new population is then used in the next iteration of the algorithm.



V. PERFORMANCE EVALUATION CRITERIA

Quantification of system performance is achieved through a performance index. The performance selected depends on the process under consideration and is chosen such that emphasis is placed on specific aspects of system performance. Furthermore, performance index is defined as a quantitative measure to depict the system performance of the designed PID controller. Using this technique an 'optimum system' can often be designed and a set of PID parameters in the system can be adjusted to meet the required specification. For a PID-controlled system, there are often four indices to depict the system performance: ISE, IAE, ITAE and ITSE. They are defined as follows:

ISE Index:

$$ISE = \int_0^\infty e^2(t)\,dt$$

IAE Index:

$$IAE = \int_0^\infty |e(t)|\,dt$$

ITAE Index:

$$ITAE = \int_0^\infty t|e(t)|\,dt$$

ITSE Index:

$$ITSE = \int_0^\infty te^2(t)\,dt$$

Therefore, for the PSO -based PID tuning, these performance indexes will be used as the objective function. In other word, the objective in the PSO -based optimization is to seek a set of

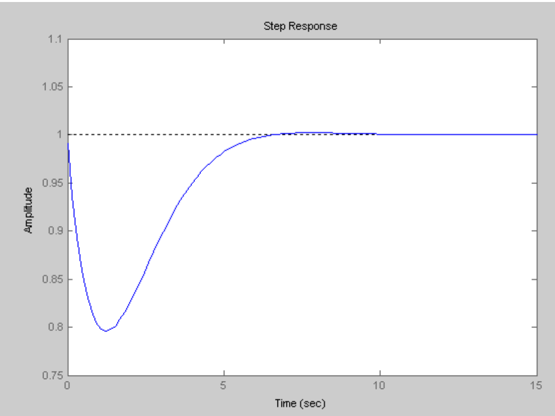
PID parameters such that the feedback control system has minimum performance index.

VI. SIMULATION AND RESULTS

Transfer function UNDER -ACUATED Maglev system:

$$G(s)= \frac{1.969 s^2 - 1.076e\text{-}016 s - 0.06076}{s^3 + 45.67 s^2 - 0.03086 s - 1.41}$$

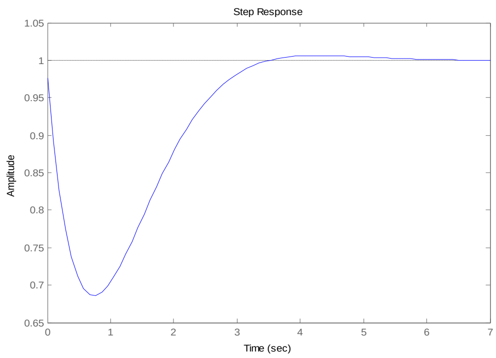
A.



Step Response Of PID Controller Using PSO

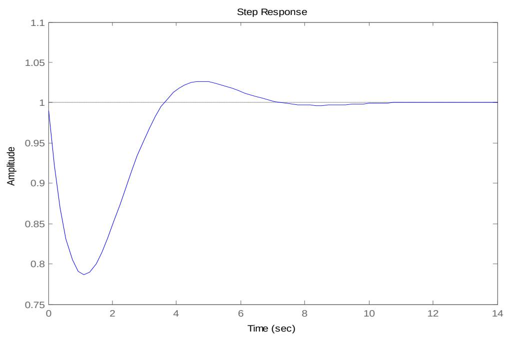
Compare results of integral errors with PID using PSO:

B



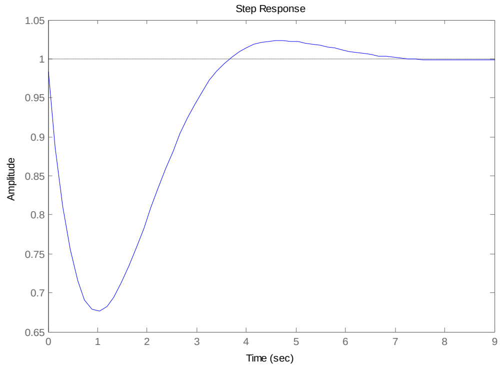
Step Response of PSO tune PID control system with IATE

C



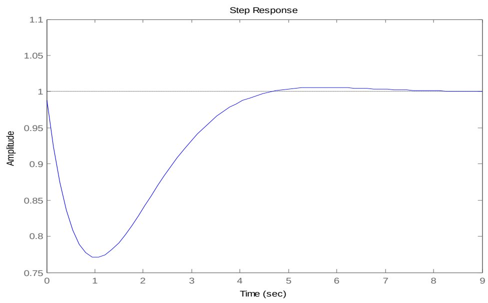
Step Response of PSO tune PID control system with IAE

D



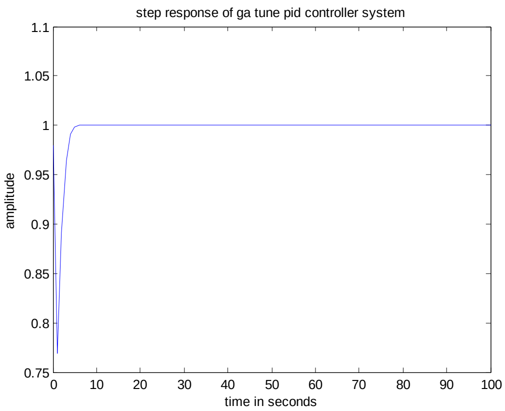
Step Response of PSO tune PID control system with ISE

F.



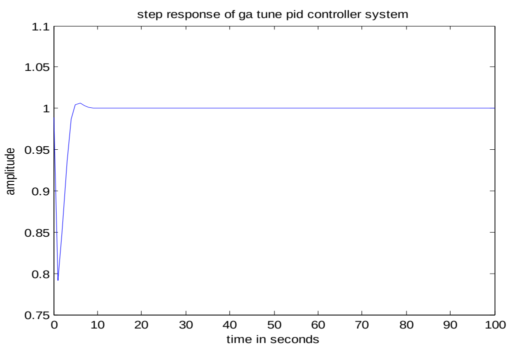
Step Response of PSO tune PID control system with ITSE

G.



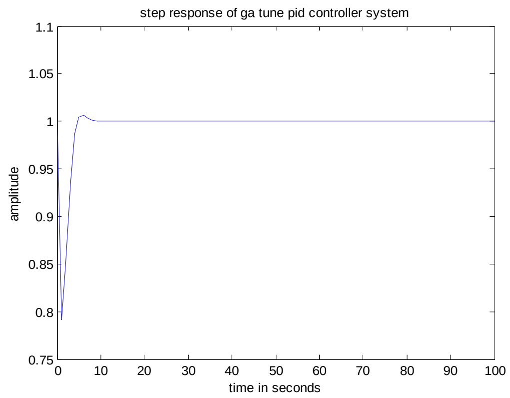
Step Response Of PID Controller Using GA

H. Compare results of integral errors with PID using GA



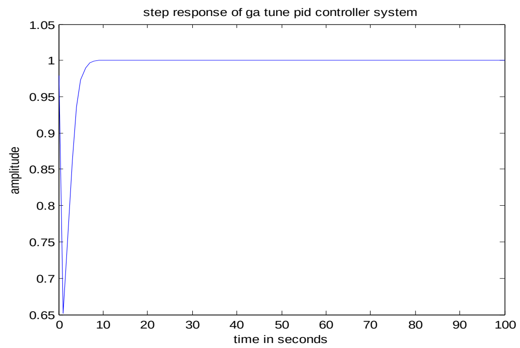
Step Response of GA tune PID control system with IATE

I.



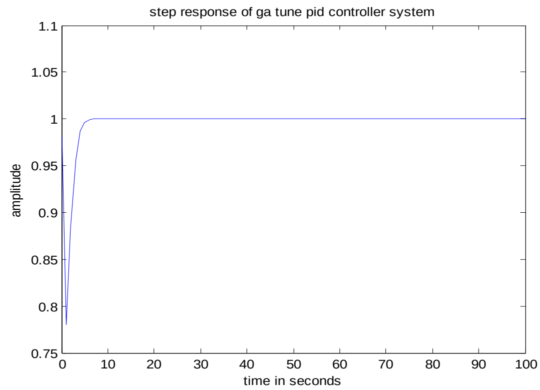
Step Response of PSO tune PID control system with IAE

J.



Step Response of PSO tune PID control system with ISE

K.



Step Response of PSO tune PID control system with ITSE

VII. TABLE 1 COMPARE RESULTS OF INTEGRAL ERRORS WITH PID USING GA

Integral of absolute time Error	**Integral of absolute Error**	**Integral of square error**	**Mean square error**
Rise Time: 0.3988	Rise Time: 0.4071	Rise Time: 2.0806	Rise Time: 1.6159
Settling Time: 6.7951	Settling Time: 6.7537	Settling Time: 6.3626	Settling Time: 4.8256
Settling Min: 0.9998	Settling Min: 0.9998	Settling Min: 0.9981	Settling Min: 0.9984
Settling Max: 1.0065	Settling Max: 1.0063	Settling Max: 1.0000	Settling Max: 1.0000
Overshoot: 0.6464	Overshoot: 0.6297	Overshoot: 0.0017	Overshoot: 0.0012
Peak: 1.0065	Peak: 1.0063	Peak: 1.0000	Peak: 1.0000
Peak Time: 5.6406	Peak Time: 5.7431	Peak Time: 11.5647	Peak Time: 8.7125

VIII. TABLE 2 COMPARE RESULTS OF INTEGRAL ERRORS WITH PID USING PSO

Integral of absolute time Error	**Integral of absolute Error**	**Integral of square error**	**Mean square error**
Rise Time: 0.4695	Rise Time: 0.1333	Rise Time: 0.0934	Rise Time: 0.4457
Settling Time: 3.2853	Settling Time: 6.7655	Settling Time: 7.7670	Settling Time: 6.5167
Settling Min: 0.9983	Settling Min: 0.9967	Settling Min: 0.9862	Settling Min: 0.9996

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Settling Max: 1.0062	Settling Max: 1.0266	Settling Max: 1.0773	Settling Max: 1.0060
Overshoot: 0.6206	Overshoot: 2.6581	Overshoot: 7.7342	Overshoot: 0.6003
Peak: 1.0062	Peak: 1.0266	Peak: 1.0773	Peak: 1.0060
Peak Time: 4.3074	Peak Time: 4.8243	Peak Time: 3.9927	Peak Time: 5.6851

TABLE 3 Compare value of kp ,ki ,kd gains of PSO

Error	**Kp**	**Ki**	**Kd**
IATE	26.4185	45.0521	21.8765
IAE	39.3089	58.5303	54.1836
ISE	5.2853	35.7490	23.8504
MSE	43.8872	45.7700	42.3102

TABLE 4 Compare value of kp ,ki ,kd gains of GA

Error	**Kp**	**Ki**	**Kd**
IATE	48.1656	49.9987	49.9975
IAE	47.8176	49.9621	49.9592
ISE	25	25	25
MSE	28.9687	49.9982	49.9847

IX. Conclusion

Maglev system can be used for transportation system friction
Less bearing and cranes etc.
For PSO Application, No. of particles is selected 50.
Rise time and Peak time is minimum for ISE.
Settling time and overshoot is minimum for IATE
Overshoot for minimum for MSE
System is stable for all error criteria.
PSO Technique is best compare to GA Technique

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