Optimization of PID Controller Gains for Identified Magnetic Levitation Plant Using Bacteria Foraging Algorithm

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Abstract
The paper presents the use of Bacteria Foraging Optimization technique in optimizing the PID gains of Feedback 33-210 Magnetic Levitation System. The system is a real-time hardware in the loop which uses Matlab Simulink real time workshop toolbox. This means that the controller system can be modified or adapted. The optimized PID gains of $K_p = 0.80431$; $K_i = 0.9800$; $K_p = 0.1121$ *resulted in steady state error of 11.8% and 0.65% for real and non-real time simulation respectively. The experimental model was obtained using Matlab system identification toolbox and the model validated with the measured output resulting in a best fit of 99.83 %. The system been open loop unstable, hence it has been identified by close loop identification. The optimized PID controller result gives a better system performance in comparism to the inbuilt PID controller.*

Keywords: *Magnetic Levitation System (MLS), BFOA, PID and System Identification.*

Introduction

Magnetic levitation (Maglev) works on the principle of an object being suspended in the air with no support other than the magnetic fields. The suspended object has no physical contact with the stable part of the system, therefore eliminating friction in the dynamics. This technology minimizes energy loss due to friction which in turn increases efficiency, reduce maintenance costs and increase the useful life of the system. Its application has rapidly increased because of its ability to eliminate energy loss due to friction, this include, high speed maglev trains, magnetic bearings which are used in suspending the rotating shaft of turbines, pumps, fans and other rotating machines [2].

The system is naturally non-linear, open loop unstable and under the influence of electromagnetic fluctuations resulting in difficulty in obtaining closed-loop stability [1].
MLS is a dynamic system that works in synergy with sensors, drivers and controllers, this presents a challenging control problem. Because it is both inherently nonlinear and open loop unstable, feedback controller must be used to stabilize it [3].

A. Basic Principle of Magnetic Levitation System (MLS)

Maglev system uses electromagnetic field to suspend ferromagnetic material and control its position against gravity and other physical forces.

Based on the difference between the desired and actual position of the object, a controller is designed to control current through the magnetic coil to generate the required force to control position of the object [4].

B. Literature Review

Many intelligent Control schemes like modified PSO, fuzzy logic, neural adaptive control have been used in maglev system. Other advanced control schemes such as feedback linearization, sliding mode control, back-stepping control, H-infinity control, quantitative feedback theory, FOPID control have also been used [4]. However, the survey is not an exhaustive one. Literature review has shown that PID controllers tuned by Bacteria foraging algorithm are relatively less explored in Maglev system 33-210.

C. PID Controller

The Controller used in this paper is PID. Despite the advancement in controller design, PID has maintained significant applications in many industrial control processes. Simplicity in design and application, cost effectiveness and acceptable robustness are some of the factors responsible for its widespread usage [4]. In this paper Bacterial foraging algorithm is used as the tool for tuning the PID parameters.

II. System Description.

Figure 1 show the basic setup of the Magnetic Levitation System (MLS) manufactured by Feedback Instruments (Model No. 33-210). It consists mainly of an optoelectronic position sensor, electromagnetic actuator coil and a ferromagnetic ball. A desktop computer is connected to MLS through Advantech card PCI-1711. Matlab and Simulink environment is used to generate the control unit. The sensor is responsible for the determination of the ball's vertical position which is recorded and passed through the Advantech card to the controller.
The controller sends current to the actuator based on the difference between the desired and measured ball position.

The actuator is an electromagnet formed by wrapping 2850turns of copper wire on a high permeable cylindrical iron core. The coil generates an upward attractive force to levitate the ball against gravity. A suitable controller is therefore required to adjust the current through the coil to suspend the ball with the mass of 21g and 50mm diameter [5].

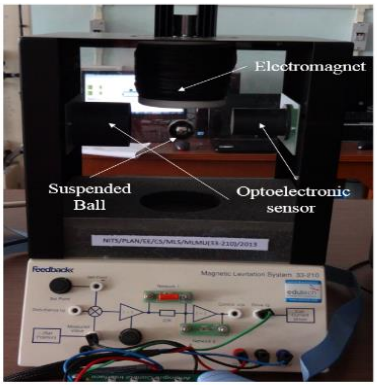

Figure 1: *MLS (Feedback 33-210)*

III. Materials and Methods

The materials used for this work includes [5]:

- Maglev 33-210 Mechanical Unit Manufactured by Feedback Inc. Co

- 33-301 Analogue Control Interface
- PC with installed PCI-1711 lab I/O Board
- Matlab R2015a
- Connecting Leads

The following steps were followed in identifying the system model experimentally.

i. Input/output selection
ii. Experiment design
iii. Collecting the data
iv. Selection of the model structure (that defines the set of possible solutions)
v. Estimation of the parameters
vi. Validation of the model (preferable with independent "validation" data)

Modelling of a system is the first and crucial step for design of a controller.

Here modelling is carried out by system identification. Maglev system being open loop unstable it was identified by close loop identification. Identification is carried out in the similar line as given in the user manual. PD controller as given in figure 2 was used for the identification purpose.

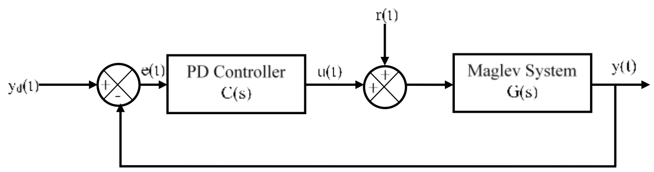

Figure 2: *MLS Identification Block diagram*

A random signal $(r(t) \in (-1;\ 1)$ was chosen as excitation input in accordance to user manual. Using $r(t)$ and output $y(t)$, close loop transfer function $T(s)$ was found using MATLAB System Identification Toolbox as equation (2) from equation (1).

$$T(s) = \frac{Y(s)}{R(s)} = \frac{G(s)}{1+C(s)G(s)} \qquad (1)$$

Where C(s) =-(4+2s)

$$T(s) = \frac{-0.515s^2-0.1415}{s^4+2.06s^3+0.06524s^2+0.5659s+0.1038} \qquad (2)$$

G(s) was validated using a different set of data and found to have 99.83% fit.

A. PID Controller Dynamics

The dynamic equation of PID controller is given with usual notation in equation (3):

$$u(t) = K_p e(t) + K_I \int_0^t e(t)dt + K_d \frac{de(t)}{dt} \qquad (3)$$

B. Controller Performance index

The quantitative measure to test the performance of a controller is known as the performance index (PI). For PID controlled systems, indices like ISE, IAE, ITSE, ITAE etc. are used. However In this paper, ISE which is given by equation (4) is used as the performance index for the optimization algorithm.

$$J = ISE = \int_0^\infty e^2(t)dt \qquad (4)$$

C. Tuning of PID Controller using BFOA

The objective in BF optimization algorithm is to find a set of PID parameters such that performance index is minimized. Its efficiency in solving real-time optimization problems arising from several application domains is responsible for the increased attention by researchers. BFOA initialization parameters used are given in table 1 and the controller parameters obtained are listed in Table 2

Table 1: BFOA initialization Parameters

Dimension of search space (p) = 3	Reproduction step (N_{re}) =4
Population size (s) =10	Elimination-dispersal (N_{ed})=3
Chemotactic step (N_c) = 4	Reproduction rate (S_r)= $s/2$
Length of swim (N_s) =4	Elimination/dispersal probability(P_{ed})=0.25

IV. Results and Discussion

Table 2 shows the PID parameters obtained using BFOA and applied for the real-time control of the MLS 33-210.

Table 2: Controller Parameters

Controller	K_p	K_I	K_d
PID	4	2	0.2
BFOA	0.80431	0.9800	0.1121

Simulated step response of the system using inbuilt PID and BFOA tuned PID controller is shown in figure 3. Figure 4 shows the real time response for a set point input at 0.0335cm.

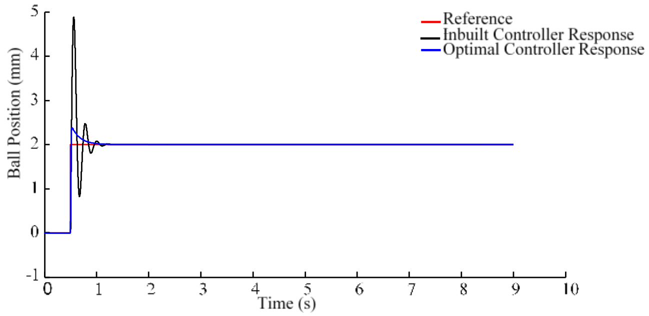

Figure 3: *Simulated step input response*

From Table 3, for a set point of 0.02cm in simulation mode, the measured ball position gave the values of 0.02013cm and 0.02474cm for optimal and inbuilt PID controllers respectively. This in turn resulted in percentage error of 0.65% position values were obtained as 0.03744cm and 0.04474cm for optimal and inbuilt PID controllers respectively resulting in the percentage error of and 23.7% respectively. Figure 4 is a sine wave simulated response.

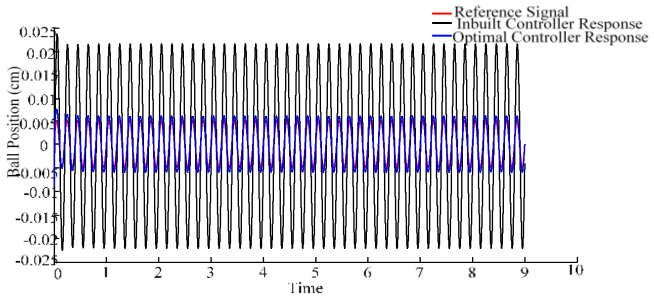

Figure 4: *Simulated sine wave input response*

For a set point of 0.0335cm in real time mode as shown in figure 5, the measured ball position gives a percentage error of 11.8% and 33.6% for optimal and inbuilt PID controller respectively as illustrated in table 4.

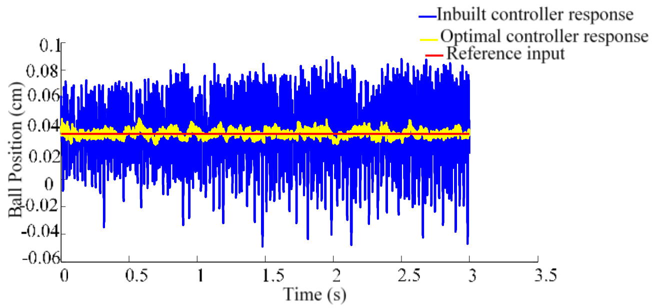

Figure 5: *Real time Set point Response*

Figure 6 and 7 shows the response of the system to sinusoidal and rectangular waveforms respectively.

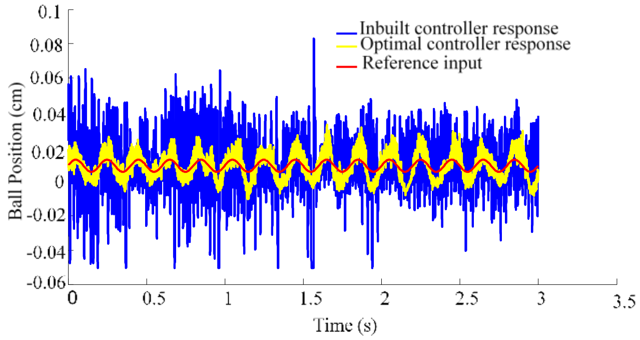

Figure 6: *Real-time system response with sine wave input*

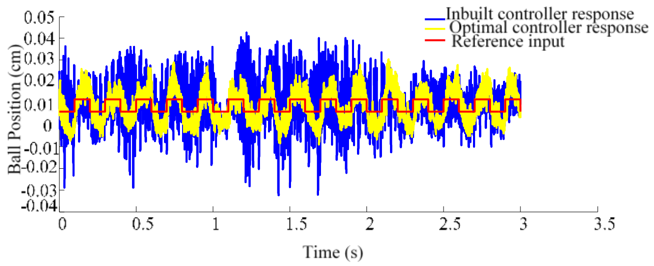

Figure 7: *Real-time system response with square wave input*

Table 3: Simulated Ball Position

Controller	**Optimal PID**	**Inbuilt PID**
Reference Position (cm)	0.020	0.020
Measured Position (cm)	0.02012	0.02474
Error (%)	0.65	23.7

Table 4: Real time Ball position

Controller	Optimal PID	Inbuilt PID
Reference Position (cm)	0.03350	0.03350
Measured Position (cm)	0.03744	0.04474
Error (%)	11.8	33.6

The optimal PID controller reduces the overshoot to 0.363% from 2.886% of the inbuilt controller in simulation mode. This result indicates that PID controller tuned by BFOA perform better than the inbuilt and FOPID tuned by PSO in the work of [4] which gives an overshoot of 0.528% in ball positioning of MLS 33-210. Result in this work are better than the work of [6] which gives an overshoot of 12%. The results from Figure 3 shows BFOA as a better choice for tuning PID controller for MLS 33-210 in terms of tracking the reference signal. This indicates improved performance in comparison with the work of [1] who obtained 5.66% overshoot using fractional-order-PID (FOPID) controller on the same plant.

Comparing the percentage errors (%) from table 3 and 4 which are obtained using equation (5), it can be clearly seen that the tracking of the reference signal is better with the optimal PID controller than the inbuilt PID controller for both simulation and real-time scenarios.

$$\%\, error = \frac{Experimental\, Value - True\, Values}{True\ Values} \times 100 \qquad (5)$$

In a similar vein, the measured ball position tracks as closely as possible the desired inputs signals for the optimal real-time scenario. This is further supported by reduction in the percentage error from 33.6% to 11.8% for inbuilt and optimal real time controller respectively. The result shows significant improvement in comparison with the work of [1] in which the percentage error for real time control was obtained as 13.04%. This therefore presents BFOA as a better tuning technique for PID controller for MLS 33-210 control than FOPID controller.

5. Conclusion and Future Scope

In this paper the inbuilt PID controller gains of MLS 33-210 manufactured by Feedback Inc. were obtained using Bacterial Foraging Optimization Algorithm and analysis made in terms of percentage error and overshoot which has direct effect on the ball levitation at the desired position as well as tracking a predetermined trajectory. The performance of the inbuilt and optimized PID controllers were compared. The Optimal PID controller gives a better performance in terms of reduced percentage error and overshoot which result in better tracking of the predetermine trajectories hence positioning of the ball at the desired position. This therefore present BFOA as better tuning technique for the PID controller parameters of MLS 33-210.

Step, sine and square wave were used as reference signals in this work. Complex reference signals can be adopted in future work. In addition future work should focus on running the system as a stand-alone without the use of a computer.

References

Chopade, A.S., Jonathan, L., Junghare, A.S. and Aware, M.V. (2014). Hardware in Loop, real time implementation of Fractional Order PID controller on Magnetic Levitation System. Paper presented at the Symposium on Advances in Control & Instrumentation (SACI-2014), Nov 24-26, 2014, Mumbai.

http://www.feedback-intruments.com/products/

Katayama, H. and Oshima, T., (2011). Stabilization of a magnetic levitation system by back stepping and high-gain observer in proc. of SICE Annual Conference (SICE). PP 754-759 Tokyo, Japan

Luiz, H.S., Carlos A.V., Vasconcelos, J., Leizer, S., and Felippe, J.A. (2010): Exact linearization and Fuzzy Logic Applied to the Control of a Magnetic Levitation System. Paper presented at IEEE World Congress on Computational Intelligence July 18-23, 2010-CCIB, Barcelona, Spain.

Lalbahadur, M., Prasanta, R. and Binoy, K. R. (2015): Design of PID and FOPID Controllers based on Bacterial Foraging and Particle Swamp Optimization for Magnetic Levitation System. Paper presented at the Indian Control Conference, Indian Institute of Technology Madras Jan.5-7, 2015, Chennai, India.

Minhaj, A., Fahad, M. H., Emdadul, M. H., Omar, F. and Mohammed, M. (2016). Design and Construction of a Magnetic Levitation System Using Programmable Logic Controller. American Journal of Mechanical Engineering. 4(3), 99-107.