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Position Tracking of ML System using CSA Based PID Controller

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Abstract: ***The classical proportional integral derivative (PID) controllers are still use in various applications in industry. Magnetic levitation (ML) systems are rigidly nonlinear and sometimes unstable systems. Due to inbuilt nonlinearities of ML systems, tracking of position of ML Systems is still difficult. For the tracking purpose of position, PID controller parameters are found by choosing Cuckoo Search Algorithm (CSA) of optimization. The ranges of parameters are customized by z-n method of parameters. Simulation results show the tracking of position of ML systems using conventional and optimized parameters obtained with the CSA based controller.***

Keywords: ***Conventional Controllers, Nonlinear Magnetic Levitation System, Optimization algorithms, z-n method***

I. INTRODUCTION

ML is a method to levitate the object in free space against the direction of gravitational force with support of magnetic field [1] [2]. Position tracking of a levitated object becomes more difficult with conventional controllers. Conventional controllers fail in producing perfect performance when the systems are nonlinear and uncertain. Zhenyu Yang et al, [3] designed an automatic Conventional controller using Non-dominated Sorting Genetic Algorithm (NSGA-II) for one dimensional Non-linear Magnetic Levitation system (NMLS). Pallav S K et al, [4] developed a conventional controller for MLS with the derivative filter concept. Marria Hypiusova et al, [5] proposed a robust PID controller to stabilize the NMLS using frequency domain approach. In this approach, the controller chosen does not guarantee stability conditions; if it fails then the controller design has to be repeated. Witchupong W et al, [6] proposed state PI controller to achieve the control over the states of the MLS. Chang-Hyun Kim [7] proposed a robust air-gap controller considering disturbance force produced by magnetic suspension for MLS.

Optimization has gained superior power and influence in many applications like industrial design and engineering. The main objective of optimization is to be maximize or minimize the main function. Hongpo Wang et al, [8] designed a controller using optimizing the control algorithms for the MLS based on the state observer. R. J. Wai et al, [9] proposed a PSO PID controller for transportation system by controlling the ML system. I. Ahmad et al, [10] designed PID controller for MLS based on GA for the parameters of the conventional controller. Literature show, that CSA satisfies the convergence requirements in global when compared with other optimization techniques, so it can guarantee the global convergence properties [11]. Civiciglu, P et al, [12] and Dhivya, M et al, [13] have made an attempt to shown CSA is very efficient for the applications of data fusion and wireless sensor networks and also mentioned the CSA produces more robust results when compared with other algorithm, PSO, ABC etc. In this paper an attempt has been made to control the MLS, by using cuckoo search based PID controller. Section II describes the real time ML system. III Section describes the design of PID controller based on cuckoo search algorithm. IV Section describes performance of cuckoo search based PID controller for position tracking of ML system, and finally section V contains our conclusions.

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II. REAL TIME MAGNETIC LEVITATION MODEL

The MLS mainly consists of Levitated steel ball, position IR sensor, controller & actuator. The levitated ball is controlled by current in the primary electrical circuit. The net force acting on the levitated ball is due to the current in the coil and distance y between coil & centre of the steel ball [2]. Fig. 1 shows the experimental setup of MLS.

Figure 1 Real time setup of MLS

The non-linear model of ML system, which is expressed in current 'i' in the coil and the position 'y' of the levitated object as

$$m\ddot{y} = mg - K\frac{i^2}{y^2} \quad \ldots (1)$$

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Where K is the constant, depends on parameters of the coil, m mass of the levitated object, g is gravitational constant.

The maglev system in (1) is of nonlinear type, it is linearized in and around equilibrium point $i_0 = 0.8\ A$ & $y_0 = 0.009$ meters.

$$f(i,y) = K\frac{i^2}{y^2} \quad \dots (2)$$

The linearized maglev system as

$$\Delta\ddot{y} = \left(\frac{\partial f(i,y)}{\partial i}\bigg|_{i_0,y_0}\Delta i + \frac{\partial f(i,y)}{\partial i}\bigg|_{i_0,y_0}\Delta h\right) \quad \dots (3)$$

Using (3), calculating partial derivatives and taking the laplace transforms,

$$\frac{\Delta y}{\Delta i} = \frac{-k_i}{s^2 - k_y} \quad \dots (4)$$

Where k_i and k_y are constants for the MLS and those are

$$k_i = \frac{2g}{i_0},\ k_y = \frac{2g}{y_0}, \quad \dots (5)$$

With reference to electrical circuit, the current in the circuit is proportional to the control voltage V

$$i = k_1 V \quad \dots (6)$$

Where, 'k_1' is proportional constant. transfer function of Maglev system is turned into

$$\frac{\Delta y}{\Delta V} = \frac{-k_1 k_i}{s^2 - k_y} \quad \dots (7)$$

In above transfer function, ΔV is change in voltage.

Adding sensor gain to above transfer function, overall transfer function of the maglev system as

$$\frac{\Delta y_{so}}{\Delta V} = \frac{-k_1 k_2 k_i}{s^2 - k_y} \quad \dots (8)$$

Here , Δy_{so} is output voltage at the sensor

For any value of the parameter of ML system without feedback has transfer function of 2nd order. The ML system has oscillations in its closed loop response. Due to closed loop response of ML systems, levitated object will fall down or will attract to electromagnet. In order to meet the performance specifications there is a need of controller.

III. PID CONTROLLER DESIGN BASED ON CUCKOO SEARCH ALGORITHM

In general, conventional controllers are preferred for Industry application, parameter of controller are searched in a certain space. Parameters found in search space satisfies the required performance indices, those are best parameters of controller. These parameters ranges can be extended based on the parameters obtained with Z-N Method [14].

In order to get optimal parameters of PID Controller, nature inspired metaheuristic algorithm is required i.e. Cuckoo search algorithm [15]. CS uses levy flights for its global search, so that it can extends the search space effectively [16]. The steps involved in finding the optimal parameters of PID controller are as follows.

A. Cuckoo Search Algorithm

Step 1:- Confirm the function to be minimum $f(x), x = (x_1, x_2, \dots, x_{nd})^T$, where nd is the number variables. Objective function as integral square error.

Generate the set of values for each variable in the function to be minimum, i.e., $x_i\ (i = 1,2,\dots,m)$ randomly, and the other parameters - size, number of variables, probability to be maximum P_k and max. no. of iteration a;

Step 2:- with reference to the function to be minimum, confirm the solution function $p(x)$, $x = (x_1, x_2, \dots, x_{nd})^T$, calculate the solution for each value of the variable, and note it.

Step 3:- record the best solution of each parameter value in every generation, using the function be minimum in Step 1 to get suboptimal values.

Step 4:- Compare the every best parameter value with the best one in last generation, and also keep the optimal value.

Step 5:- if the solution is not changed upto max. no. of iterations a or changes less than value 0.05 in max. no. of iterations a, then go for next step, Otherwise, skip the next step.

Step 6:- In each iteration, cuckoos can founds the good parameter value & bad parameter value, replace the poor parameter value form an intermediate group with an optimal parameter value generated during the previous iteration. Mutate the optimal parameter value by solution obtained in 2 step, regarding the parameter values except the optimal one as sub-optimal parameter values & mutate the sub-optimal parameter values by 3 step.

Compare the solutions of current and previous optimal, if current solution is best, then indicate current solution is optimal and also update it as optimal solution, otherwise, repeat the process. If max no. of times the variation is not successful, then execute 8 step.

Step 7:- compare probability to be maximum P_k with an arbitrary value $r \in (0,1)$ if $r > P_k$, then change arbitrary $x_i^{(a+1)}$. If no change, then hold the best group of parameter values.

Step 8:- terminate condition, to meet the max no.iterations a or did not met the minimum error ε condition. If do not attained, then return to 2 step. Otherwise execute the global optimal values.

IV. SIMULATION RESULTS

In this, Conventional controller is designed for position tracking of ML System. The electromagnetic coil is placed on top of the ML System. IR sensor is placed on opposite sides of the levitated object. It is easy to sense the position of levitated object. If the levitated object is near to electromagnetic coil, it will experience an attractive force. Otherwise it will fall down.

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Controller is required to maintain the levitated object in free space, i.e to control the force due to electromagnetic coil, so that position tracking of ML system can be achieved. The response of ML system is undamped and oscillatory. The designed controller should be capable of improving the response requirements. The parameters of conventional controller obtained with z-n method are $k_p = 4.0$, $k_i = 0.05$ and $k_d = 0.2$. The other parameters used in simulations as well as in real time application are in table 1

Table 1 Maglev system parameters

Parameter	Value	observation
m	0.011 kg	Mass of levitated object
y_0	0.0078 m	Equilibrium Position
i_0	0.421 A	Equilibrium current
k_i	0.4678 N/A	Current amplification gain
k_1	0.1 A/V	Control voltage gain
k_2	Aprox. 33333 V/m	sensor gain

CSA is utilized to find optimal parameters of the conventional controller by minimizing the objective functions like ISE, IAE etc. [14-15]. In this paper integral square error (ISE) performance index is chosen as objective function. The search space for the CSA is chosen based on the parameters tuned using Z-N method and also used these parameters for first iteration. The remaining parameters are chosen randomly around alpha by a guess. In order to get global optimum solution, care should be taken while choosing search space.

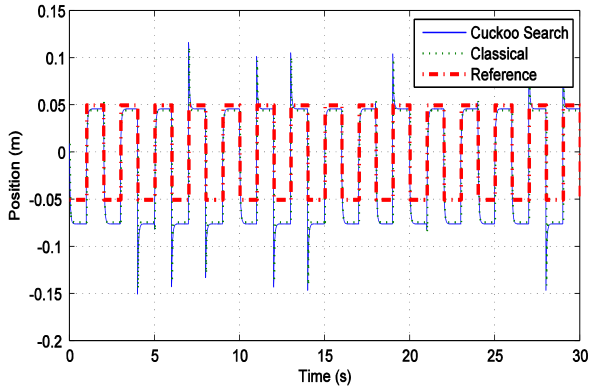

Figure 2 position tracking comparison of ML system in simulation

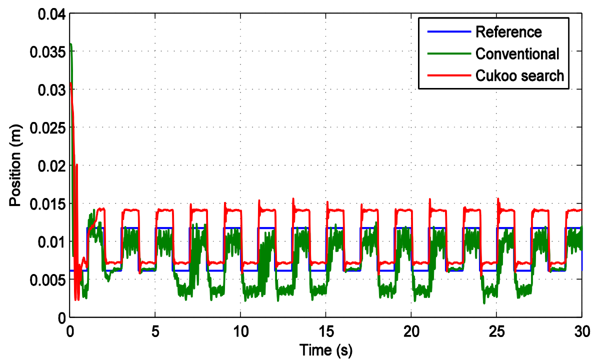

Figure 3 position tracking comparison of Real Time ML system

The comparison of position tracking response of the ML systems with PID controller using CSA and Z-N Method are in Figure 2. For the same parameters of the PID controllers has been implemented for real time ML system, which is shown in Figure 3.

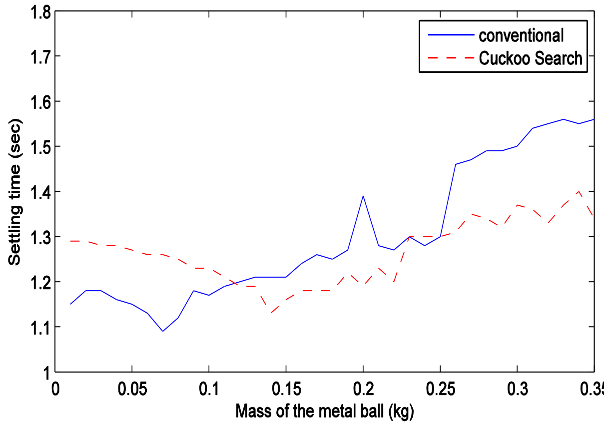

Figure 4 settling time comparison of ML system in real time

Fig. 4 shows the settling time variation of ML system for different values of mass of the levitated object. Conventional controller produces large variation in settling time as increasing the mass of the ball from minimum to maximum. As compared with conventional controller, cuckoo search based PID controller produces small variation in settling time as increasing the mass of the ball from minimum to maximum. Conventional controller needs to change the design parameters, if there is any variation in the system parameters. Cuckoo search based PID controller do not need any variation in the design parameters.

V. Conclusions

CSA based PID controller is designed for position tracking of ML system. The parameters obtained with CSA are optimized which are used in simulation as well as real time. CSA based PID controller guarantees the improvement in performance required, by minimising the integral square error of the ML system. The results are made comparison with conventional controller and CSA based PID controller. The conventional controller needs continuous updation if there is any change in the ML system parameters. CSA based PID controllers provides better performance when there is any change in ML system parameters.

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