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Execution of various Types of Controllers to Fix the Ball Position of Magnetic Levitation System

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ABSTRACT: Objective of the work is to control a magnetic levitation system with various control mechanisms to levitate and stabilize a spherical steel ball at a desired position using controllers. This paper tells about Proportional Integral controller, Corresponding Integral Derivative controller and direct quadratic controller for repaying a physical attractive levitation framework. Due to the implementation of controllers, the result shows that increasing transient response of the magnetic levitation system can be changed into a desired manner. The results are verified using simulation and experimental methods. Both the simulation and experimental analysis has been made to stabilize the ball position in the desired position. Controllers like PI, PID and LQR are designed to get fix the ball position in the desired level. Finally LQR controller is given the best result for step, square and sine inputs when compared to PI and PID controller. The work has been extended with various other intelligent and model based controller in future.

Keywords: LQR, Magnetic levitation system, PI and PID.

Abbreviations: LQR, linear quadratic regulator; PI, proportional integral; PID, proportional integral derivative; MIMO, multi input multi output.

I. INTRODUCTION

Attractive levitation or maglev is a framework, wherein object is suspended with no help other than attractive fields. Attractive power is utilized to check the impacts of the gravitational quickening and some other increasing speed.

The two essential issues engaged with attractive levitation are (i) lifting powers which giving an upward power adequate to balance gravity and (ii) security which guaranteeing that the framework doesn't precipitously slide or flip into an arrangement where the lift is killed. It was explained about the levitation force between a small mixed state superconducting cylinder and a magnetic ring was measured [1].

The reliance of the levitation power was analyzed on the size of the superconductor just as the magnet. The suspending gadget was resolved to be inflexible. Stettinger *et al.,* told about the situation of a definitive power of levitation relies on the size of the superconductor and the magnet [19].

Werfel *et al.,* describes the configuration of a nonlinear system is linearized around the point of operation [20]. Using the obtained linear method, two control loops, an inner current loop and an outer location loop are built.

Review recent progress in this field and discuss how the design of cryogenic and HTS components can have a positive effect on the efficiency of levitation and screening [21]. The properties of cryogenic systems and mobile application devices should be compared with stationary HTS systems in their complexity and necessary robustness, and the impact of various cooling options has to be considered.

The authors clarified the calculation tunes the parameter of the PID controller while limiting the exhibition list of the framework, for example, indispensable time weighted supreme mistake (ITAE) and vital time weighted square blunder (ITSE) [13, 14, 22-24]. The adequacy of the proposed controller is approved by contrasting it and the traditional tuning standard [22].

The work proposes a pragmatic nonlinear controller for the MIMO levitation framework. Right off the bat, the numerical model of levitation modules is created and the upsides of the control plot with attractive transition input are dissected when contrasted and the present criticism [15]. At that point, a back stepping controller with attractive motion input dependent on the scientific model of levitation module is created.

A programmed attractive levitation offset with an affectability of 2.5×10^{-8} N and a period steady of 0.1 s is structured [2]. The equalization was tried in probes the dynamic impact energy for heterogeneous compound responses.

Scientific and technological work on the construction of transport with the vehicle's magnetic levitation was examined and the key stages of design of such transport were analyzed [3]. An iterative algorithm was built for the design of the electromagnets used in magnetic levitation systems and the lateral stabilization of high-speed ground transport.

This paper uses the extremum chasing (ES) strategy to tune PID parameters on-line to improve the consistent state execution of the framework with hardly any motions [7]. A "tested information" structure is utilized to acquire a moving window guess of the consistent state conduct, prompting a discrete-time ES tuning for the decentralized PID parameters.

They present procedures for design and control of a passive maglev carrier network. Mechanical experiments were conducted to determine the configuration and position of the levitation magnets to achieve stable and effective levitation [16]. The key problem in the control design is that as it moves, the positions and magnitudes of the levitation forces are not constant along the edge of the moving platform.
A robust self-tuning integral of error signum (RISE) dependent controller is designed and used in this study to control a magnetic levitation (maglev) device [4]. Like the traditional RISE unit, the control architecture uses the 'tanh' function instead of the 'signum' function to get a smoother control signal. The increases of the controller are refreshed by a period differing update rule.
The work discuss the question of state observation for sensorless regulation of magnetic levitation systems, i.e. controlling the location of a levitated body measuring only the electrical supply voltage and current [5].
Boonsatit and Pukdeboon (2016) addresses the issue of two control laws dependent on sliding-mode ideas is made. To control an attractive levitation framework a versatile sliding mode controller is intended for the primary controller. The other controller is additionally evolved by joining a quick terminal sliding mode control strategy with a versatile system [6].
The controller is combined with 1:1 internal resonance to the main system. Multiple-scale perturbation technique is used to achieve an approximate solution that clarifies nonlinear behavior for the entire system's amplitude as well as phase [8]. The effects of the magnitude of the time delay are examined to demonstrate the secure region of activity.
The interaction force occurring in the device superconductor – array of magnets is determined by the finite-element method based on a critical state model [9]. Optimum magnetic system configurations are defined in which maximum values are produced for both attractive and repulsive forces.
Novel method is presented in this work for estimating the position of a self-sensing magnetic levitation device, based on a technique for identification of at least squares [10]. Finally, simulation experiments and measurement tests on a test bench show the excellent efficiency and the high robustness of the proposed position estimator.
The HTS bulk was shifted down and up three times in this study between the field-cooling position and the working position above the PMG, followed by a 300 s relaxation test at the minimum height level explained [11].
Magneto impedance sensors are utilized right now identify the area of a suspended slider, whose size is 7.2 mm square and 2 mm thick. This magneto impedance sensor is accessible financially and works based on a direct connection between the outer attractive field and the yield voltage [12].
The qualities of levitation power unwinding between the HTS mass and the NdFeB guideway by means of an analysis in which an electromagnet-produced outside attractive field AC is utilized to recreate the time-differing outer attractive field initiated by the guideway's in homogeneity [17]. This paper provides clear experimental proof that the RBF-ARX model is capable of capturing and quantifying behavior of a nonlinear and rapid response system not only globally, but also locally, and the model-based predictive control strategy is capable of operating very well across a wide range of nonlinear system operations [18].
The frame work of the paper is explained as follows: In section II, the magnetic levitation unit Physical model is obtained. PID and LQR controllers are designed in section III. Results and conclusions are offered in section IV, V respectively.

II. PHYSICAL MODEL

The Maglev arrangement fills in as a basic model of gadgets, which are turning out to be increasingly more well-known as of late for example Maglev trains and attractive direction. Maglev trains are as of late tried and a few lines are as of now accessible as in Shanghai. Attractive course are utilized in turbines for a similar explanation as Maglev trains are being fabricated, which is low rubbing in the bearing itself. Effectively numerous turbines are utilized financially where the rotating shaft is suspended with attractive transition. Some other attractive bearing applications incorporate siphons, fans and other turning machines.
The attractive levitation frameworks are engaging for their extra plausibility of dynamic vibration damping. This should be possible by different control calculations executions and with no alterations to the numerical pieces of the entire framework.

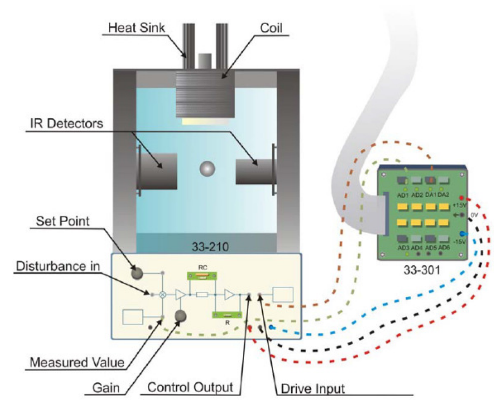

Fig. 1. Maglev Mechanical Unit.

III. CONTROLLER DESIGN

A. PID Controller Design

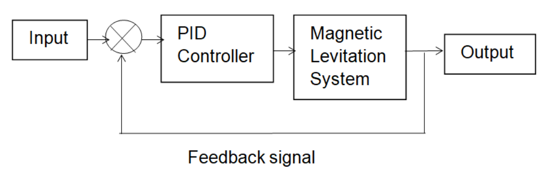

Fig. 2. Block Diagram of PID controller.

PID controller was designed by [25] and the proportional, integral and the derivative values were extracted using MATLAB Simulink.
— Kp = 0.000547
— Ki = 5.94e-09
— Kd = 12.6

B. LQR Controller Design

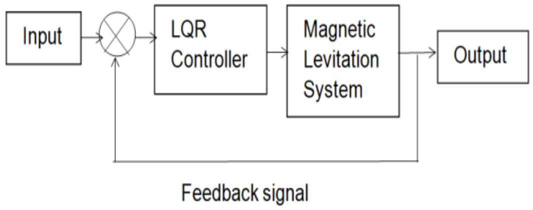

Fig. 3. Block Diagram of LQR controller.

The LQR gain values were found out using the Ricatti equation

$$A^TP+PA-PBR^{-1}B^TP+Q=0 \quad (1)$$

Where,

$$A=A-BR^{-1}B^T \quad (2)$$

$$Q=Q-BR^{-1}B^T \quad (3)$$

$$K=R^{-1}B^TP \quad (4)$$

$$A = \begin{bmatrix} -70.1594 & 849.1789 & 0.5957 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix}$$

$$B = \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$$

$$C = [0 \quad 0 \quad 77.44]$$

$$D = 0$$

$$Q = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$R = 1$$

Substituting the values of A, B, Q, R in Eqns. (1), (2) and (3)

The gain values obtained are

$K_1 = 0.0211$

$K_2 = 1.6985$

$K_3 = 0.0018$

IV. RESULTS AND DISCUSSION

Simulation response [26] of the ball position and control signal of a Magnetic Levitation system using PD controller for step input of 0.005 is shown in Fig. 4 (a) and (b) respectively.

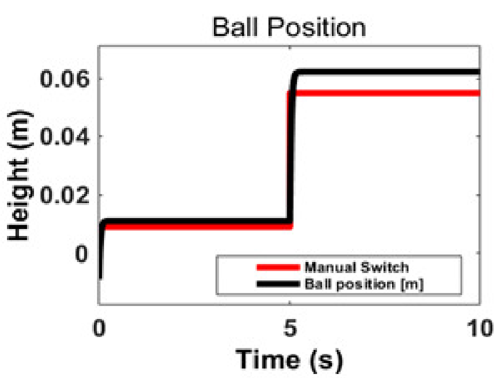

Fig. 4. (a) Simulation step response of the ball position using PD controller.

Initially the step input of 0.01 m is given up to 5 sec, after that it increases from 0.01 m to 0.055 m. The ball position tracks the input but there is some deviation is present using PD controller.

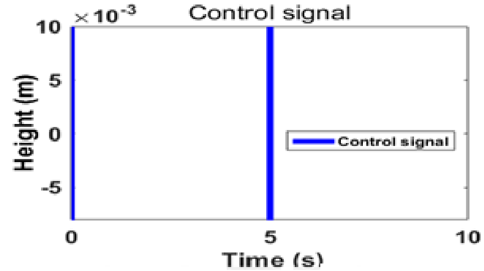

Fig. 4 (b) Simulation step response of the control signal using PD controller.

Simulation response of the ball position and control signal of a Magnetic Levitation system using PD controller for square input of 0.005is shown in Fig. 5 (a) and (b) respectively. In the square input, there is offset persists.

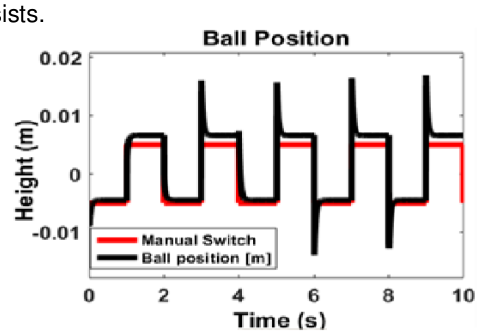

Fig. 5 (a) Simulation square response of the ball position using PD controller.

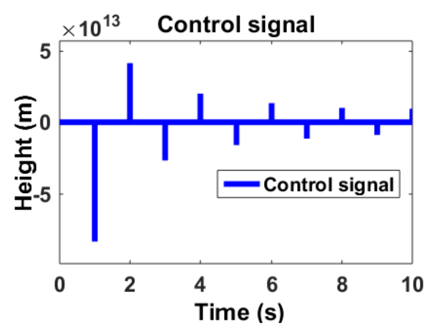

Fig. 5 (b) Simulation square response of the control signal using PD controller.

Simulation response of the ball position and control signal using PD controller for sine input of 0.005 is shown in Fig. 6 (a) and (b) respectively. The output follows the input, but there is some deviation.

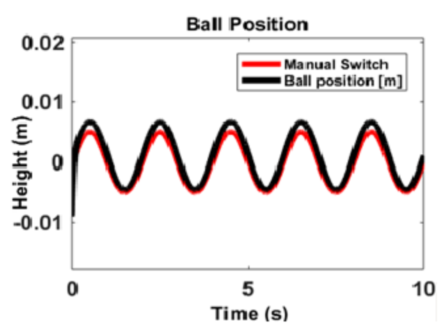

Fig. 6 (a) Simulation sinusoidal response of the ball position using PD controller.

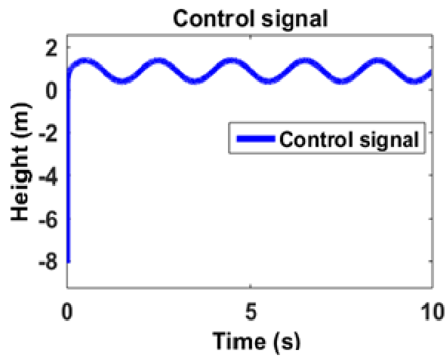

Fig. 6 (b) Simulation sinusoidal response of the control signal using PD controller.

Simulation response of the ball position and control signal of a Magnetic Levitation system using PID controller for step input of 0.055 is shown in Fig. 7 (a) and (b) respectively. The values of PID parameters are K_p=32, K_i=0.05 and K_d=0.17 respectively. Initially the input up to 5s is 001m, at 5s the ball position is increased from 0.01 to 0.055m. In the initial period the output follows the input, after 5s there is some small deviation is recorded.

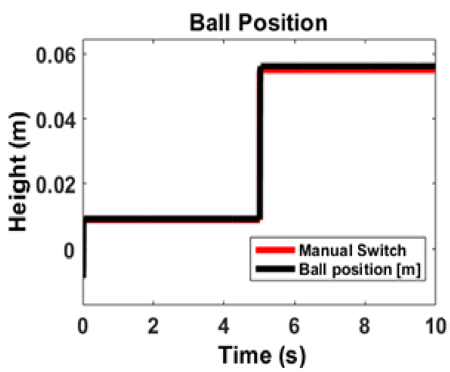

Fig. 7 (a) Simulation step response of the ball position using PID controller.

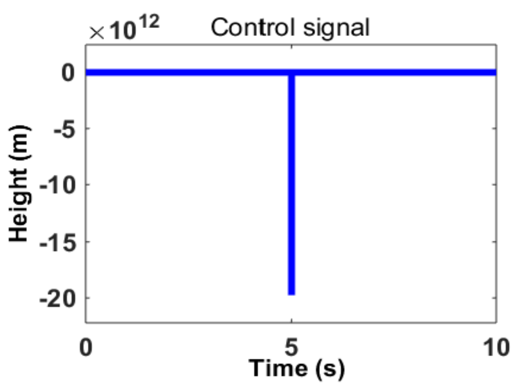

Fig. 7 (b) Simulation step response of the control signal using PID controller.

Simulation response of the ball position and control signal of a Magnetic Levitation system using PID controller for square input of 0.05is shown in Fig. 8 (a) and (b) respectively. In the square input the output follows the input.

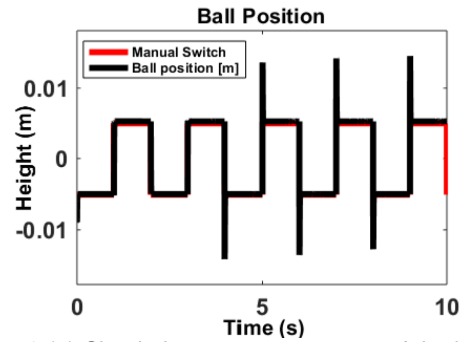

Fig. 8 (a) Simulation square response of the ball position using PID controller.

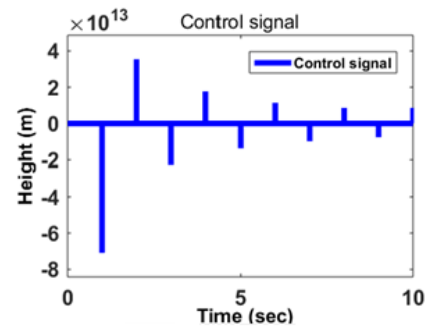

Fig. 8 (b) Simulation square response of the control signal using PID controller.

Fig. 9 (a) and (b) are the simulation response of the ball position and control signal of a Magnetic Levitation system using PID controller for sinusoidal input of 0.05m. The output follows the input of the slanting portion of the input, but in the peak position there is some difference between input and output.

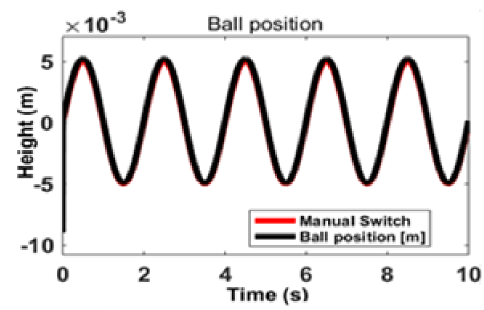

Fig. 9 (a) Simulation sinusoidal response of the ball position using PID controller.

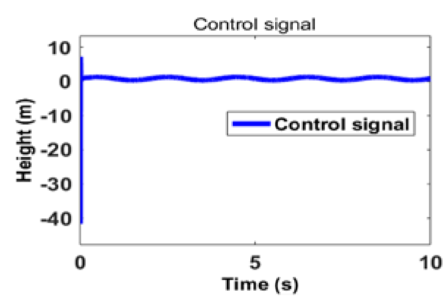

Fig. 9 (b) Simulation sinusoidal response of the control signal using PID controller.

Simulation response of the ball position and control signal of a Magnetic Levitation system using LQR controller (before tuning), for step input of 0.055 is shown in Fig. 10 (a) and (b) respectively. The values of Q= $\begin{bmatrix} 7444.7 & -3431 & -2442778 \\ -3486 & -50.88 & -1017 \\ -2444112.83 & -35671 & -713436 \end{bmatrix}$. Initially the output tracks the input up to 5s, after that some small deviation is present in the system.

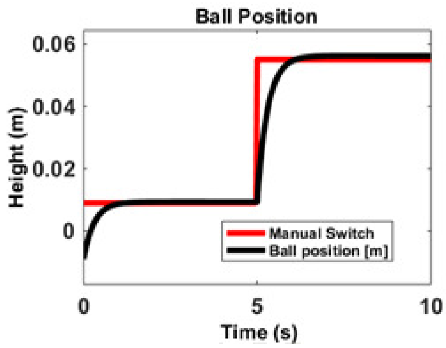

Fig. 10 (a) Simulation step response of the ball position using LQR controller before tuning.

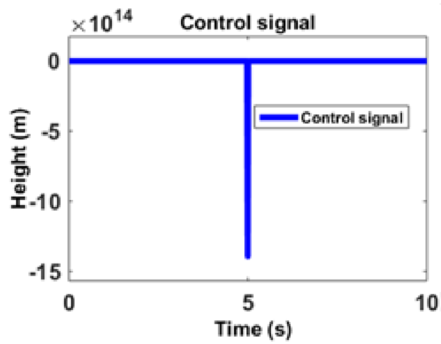

Fig. 10 (b) Simulation step response of the ball position using LQR controller before tuning.

Simulation response of the ball position and control signal of a Magnetic Levitation system using LQR controller (before tuning), for square input of 0.005m is shown in Fig. 11 (a) and (b) respectively. In square input also there is some deviation in the output.

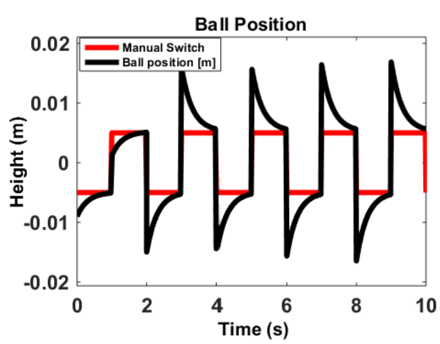

Fig. 11. (a) Simulation square response of the ball position using LQR controller before tuning.

Simulation response of the ball position and control signal of a Magnetic Levitation system using LQR controller (before tuning) for sinusoidal input of 0.005are shown in Fig. 12 (a) and (b) respectively.

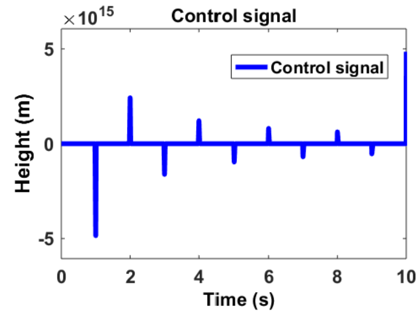

Fig. 11 (b) Simulation square response of the ball position using LQR controller before tuning.

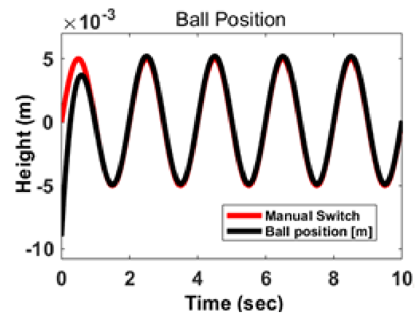

Fig. 12 (a) Simulation sinusoidal response of the ball position using LQR controller before tuning.

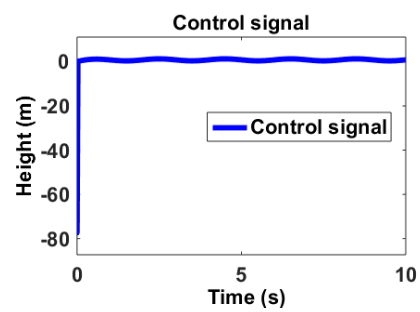

Fig. 12 (b) Simulation sinusoidal response of the control signal using LQR controller before tuning.

Simulation response of the ball position and control signal of a Magnetic Levitation system using tuned LQR controller, for step input of 0.005mis shown in Fig. 13 (a) and (b). The values of Q= $\begin{bmatrix} 90 & -544 & -38176 \\ -544 & -8 & -159 \\ 38189 & 557 & -11147 \end{bmatrix}$. Here the output follows the input initially, after some time there is a very small deviation in the step input.

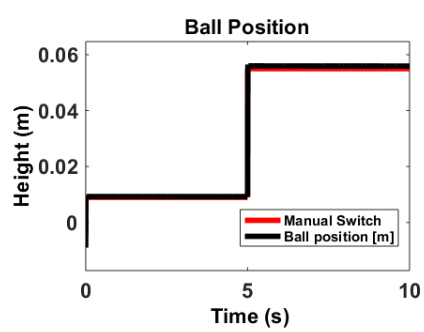

Fig. 13 (a) Simulation step response of the ball position using tuned LQR controller.

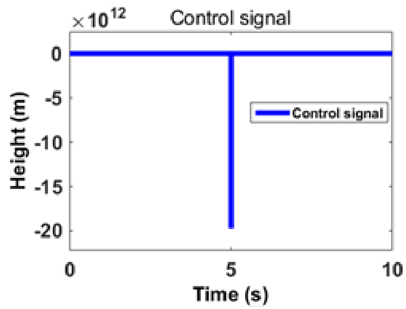

Fig. 13 (b) Simulation step response of the control signal using tuned LQR controller.

Fig. 14 (a) and (b) shows the simulation response of the ball position and control signal of a Magnetic Levitation system using tuned LQR controller, for square input of 0.005m. Simulation response of the ball position and control signal of a Magnetic Levitation system using tuned LQR controller, for sinusoidal input of 0.005m is shown in Fig. 15 (a) and (b) respectively. In square and sine input the output perfectly follows the input.

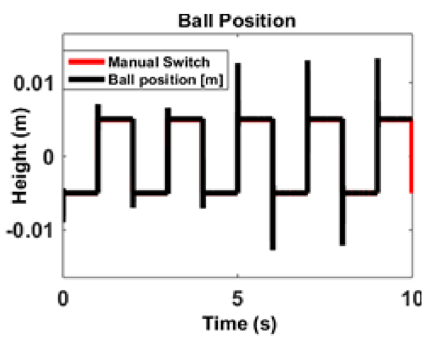

Fig. 14 (a) Simulation square response of the ball position using tuned LQR controller.

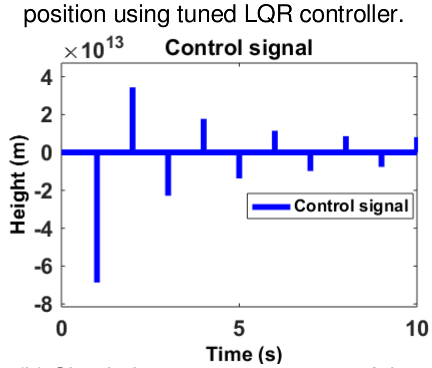

Fig. 14 (b) Simulation square response of the control signal using tuned LQR controller.

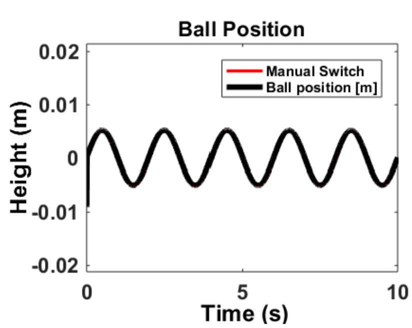

Fig. 15 (a) Simulation sinusoidal response of the ball position using tuned LQR controller.

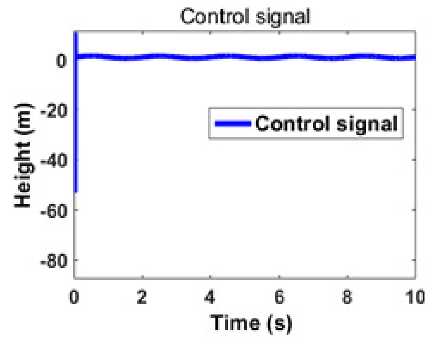

Fig. 15 (b) Simulation sinusoidal response of the control signal using tuned LQR controller.

V. CONCLUSION

In this paper, stabilization of sphere ball was done using various controllers like PI, PID, and LQR. Due to the implementation of controllers the position of the ball can be done in desired position using MATLAB tool. Finally LQR controller gives better position of the ball.

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Conflict of Interest. The authors declare no conflict of interest.

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