Final Project

Adaptive Controller Design for Magnetic levitation System

Me 6654 Adaptive Control Systems

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Introduction:

The electromagnetic levitation system controls the magnetic field generated by an electromagnet to levitate a small magnet in midair. [1] The small magnet levitates in the air and can be moved vertically by three push button. This system is becoming very popular day by day. It is used in different fields such as frictionless bearings, high-speed Magnetic Levitation passenger trains, levitation of wind tunnel models, vibration isolation of sensitive machinery, levitation of molten in induction furnaces, levitation of slabs during manufacture etc. [2]

Background:

One can design robust PI-PD controller to keep a small magnet suspended in the air in the desired position by maintaining the balance between the magnetic force and ball's weight. [2] One can build the neural network control system to get the stability of the system. [3] Fuzzy logic controller can be used for controlling magnetic levitation system. [4] In this method, the fuzzy logic controller brings the magnetic levitation system to a stable region by keeping a magnetic ball suspended in the air.

Mathematical Modeling of the System:

The model of the electromagnetic levitation system is shown in Figure 1 [1], where *R* is the resistance of the coil, *L* is the inductance of the coil, *v* is the voltage across the electromagnet, *i* is the current through the electromagnet, *m* is the mass of the levitating magnet, *g* is the acceleration due to gravity, *d* is the vertical position of the levitating magnet measured from the bottom of the coil, *f* is the force on the levitating magnet generated by the electromagnet and *e* is the voltage across the Hall effect sensor.

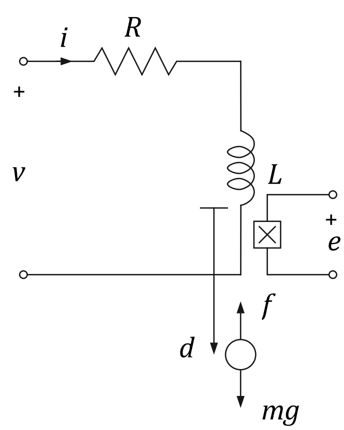

Figure 1. Electromagnetic levitation system model.

The force applied by the electromagnet on the levitating magnet can be closely approximated as

$$f = k\frac{i}{d^4},$$

where *k* is a constant that depends on the geometry of the system. The voltage across the Hall effect sensor induced by the levitating magnet and the coil can be closely approximated as

$$e = \alpha + \beta \frac{1}{d^2} + \gamma i + n,$$

where α, β and γ are constants that depend on the Hall effect sensor used as well as the geometry of the system and n is the noise process that corrupts the measurement [2]. It follows from Newton's second law that

$$m\ddot{d} = mg - k\frac{i}{d^4}.$$

From the detail calculations in [1] and [5] we get the transfer function as,

$$P(s) = \frac{\frac{\gamma}{L}s^2 + [\frac{2\beta g R(gmR)^{3/4}}{Lu_e(ku_e)^{3/4}} - \frac{4\gamma g(gmR)^{1/4}}{L(ku_e)^{1/4}}]}{(s + \frac{R}{L})[s^2 - \frac{4g(gmR)^{1/4}}{(ku_e)^{1/4}}]}$$

Using the values from the document we get,

$$P(s) = \frac{31.9361s^2 + 1.1132 \times 10^5}{(s + 160.3460)(s^2 - 1.9620 \times 10^3)}$$

Working principle:

Hall effect sensor is used to measure the vertical position of the small magnet. A microcontroller is used for controlling the current of electromagnet. The system has three types of reference signal which is sinusoidal, square or sawtooth. Magnetic force is used to counteract the effects of the gravitational acceleration and any other accelerations. [6]

Problems in Current System:

There is a problem in this current system. When levitation occurs, the small magnet is not stable in air because electromagnetic force is very sensitive and there is a noise that creates acceleration forces on the steel ball resulting the instability due to existence of positive poles causing the steel ball to move into the unbalanced region. [2] It oscillates over the vertical region. To stable the system, one need to design a controller which can solve this problem.

System Identification:

For deigning the adaptive controller, one first need to figure out the experimental transfer function. The transfer function from mathematical model is of 3rd order. For figuring out the experimental transfer function, one can use system identification toolbox in matlab. For experiment, I used Arduino to take data from the system. Following is the Simulink model, one can use for take data from the system.

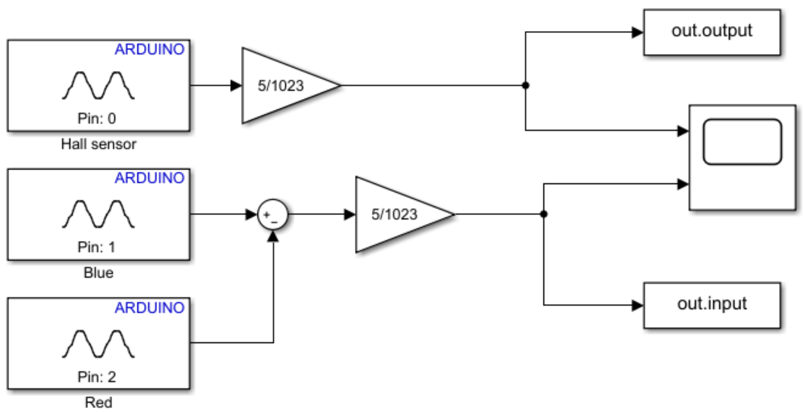

Figure 2: Simulink model for exporting data for develop experimental transfer function

From mathematical model, it is clear that displacement is our desired output and it is dependent on current and hall voltage. That's why in simulation model, hall sensor voltage is used as output data. Voltage difference between two end of the electromagnet is taken as input in the Simulink model. One set the small magnet in the stable position and collect data by using this Simulink model. Data is exported to workspace in matlab for using it for system identification. Then, system identification toolbox is used for developing the experimental transfer function. The transfer function found from there is given below.

$$G(s) = \frac{0.01964}{s^2 + 0.54s + 0.0045}$$

Following is the validation of this transfer function.

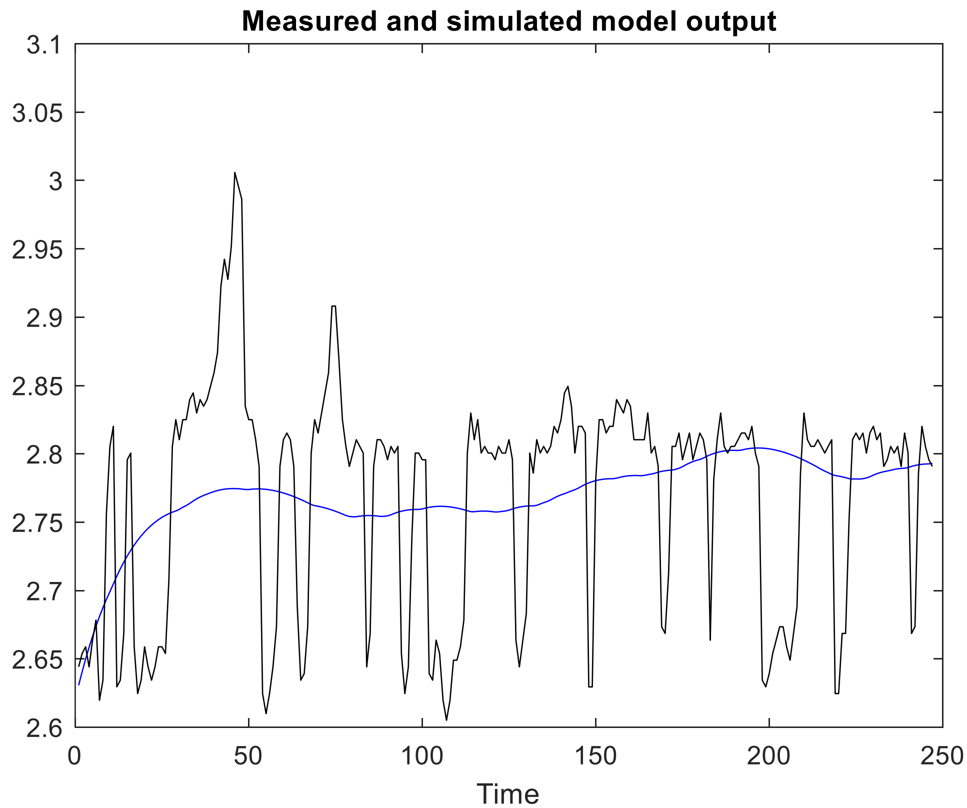

Figure 3: validation output of the transfer function

Control of plant output with PID controller:

One can use PID controller to control the desired output. Experimental transfer function G(s) is used as plant transfer function. Full Simulink model is given in figure 4.

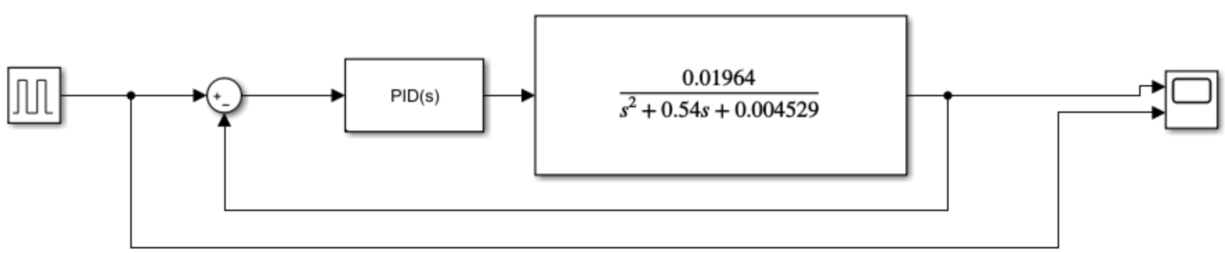

Figure 4: Simulink model with PID controller

PID auto tuner is used to find the desired output. Pulse generator is used as input. Response is shown in figure 5.

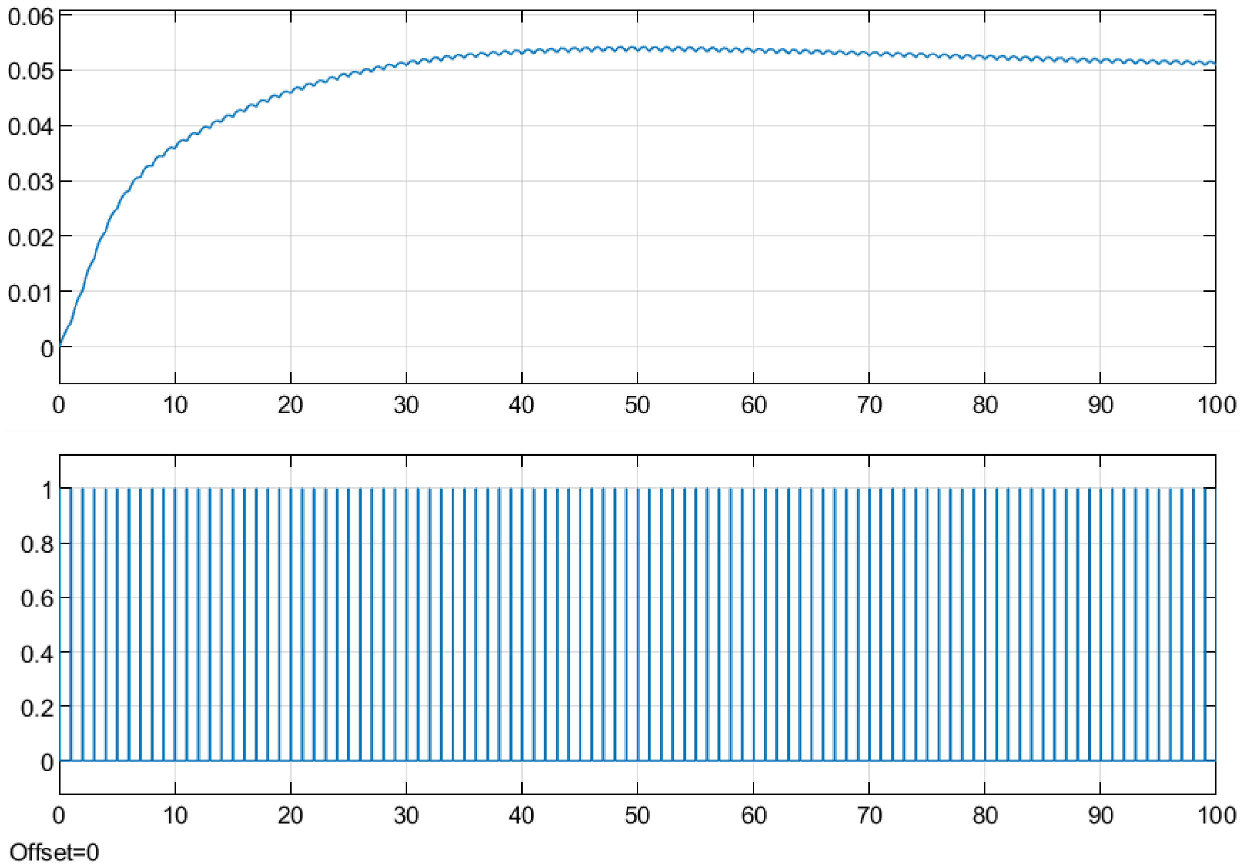

Figure 5: Response from PID controller

Then this is implemented by Arduino to real system. Simulation of implementation is given in figure 5.

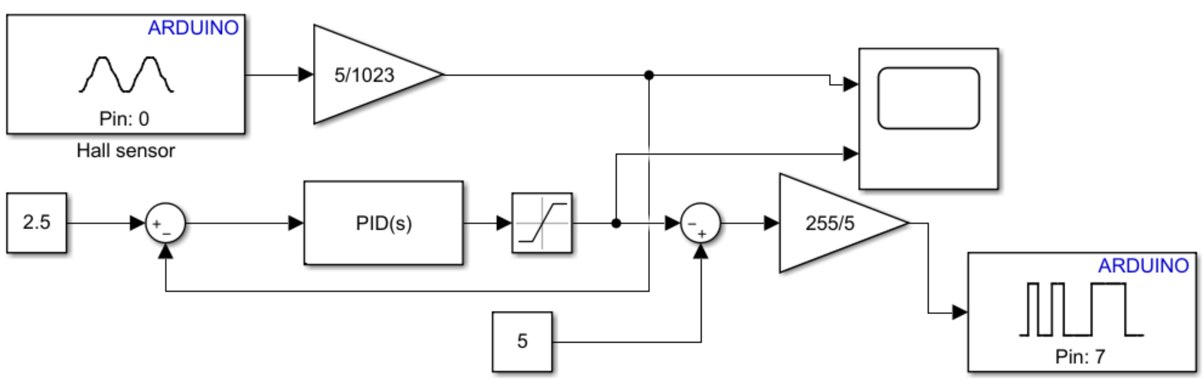

Figure 6: Implementation of PID controller to magnetic levitation system

Limitation of PID controller:

There is some limitation of PID controller. The problem with the PID controller is that it can not adapt with the change of the transfer function. That means it is not adaptive.

Design of Self-Tuning Regulator (STR) Controller:

Our plant transfer function from system identification,

$$G(s) = \frac{0.01964}{s^2 + 0.54s + 0.0045}$$

From the plant transfer function,

B = [0.01964] & A = [1 0.54 0.0045]

Model transfer function,

$$\frac{Bm(s)}{Am(s)} = \frac{\omega^2}{s^2 + 2\zeta\omega s + \omega^2}$$

Now,

$$\deg(A_m)=\deg(A)=2$$

$$\deg(B_m)=\deg(B)=0$$

$$\deg(A_0) = \deg(A) - 1 = 2-1=1$$

$$\deg(S)=\deg(R) =1$$

Let's choose,

$$A_o=s+a_o$$

Control given by,

$$AR+BS=A_c$$

$$AR + BS = A_m A_c$$

$$(S^2+0.54S+0.0045)\,(s+r_1) + (0.01964)\,(S_0S+S_1) = (s + a_0)(s^2 + 2\zeta\omega s + \omega^2)$$

Equating coefficient of equal power of S:

$$0.54 + r_1 = 2\zeta\omega + a_0 \quad (1)$$

$$0.0045 + 0.54r_1 + 0.01964s_0 = \omega^2 + 2\zeta\omega a_0 \quad (2)$$

$$0.0045r_1 + 0.01964s_1 = a_0\,\omega^2 \quad (3)$$

Since no zero's are cancelled,

$$B^+ = 1 \text{ and } B^- = B = 0.01964$$

For our desired output, let's choose a_0=1, ω=1 & ζ= 0.7

Now,

$$T= \frac{\omega 2}{b}(s + a0)$$

Solving equation 1,2 &3, following parameters are obtained.

$$r_1 = 1.86,\ s_1 = 46.65\ \&\ s_0 = 70.82$$

$$T = \frac{s+1}{0.01964}$$

$$R = s + 1.86$$

$$S = 70.82s + 46.65$$

Therefore,

$$\frac{T}{R} = \frac{s+1}{0.1964s + 0.03653}$$

$$\frac{S}{R} = \frac{70.82s + 46.65}{s + 1.86}$$

Simulink Model of STR controller:

Simulink model of STR controller and response is given in figure 6 & 7.

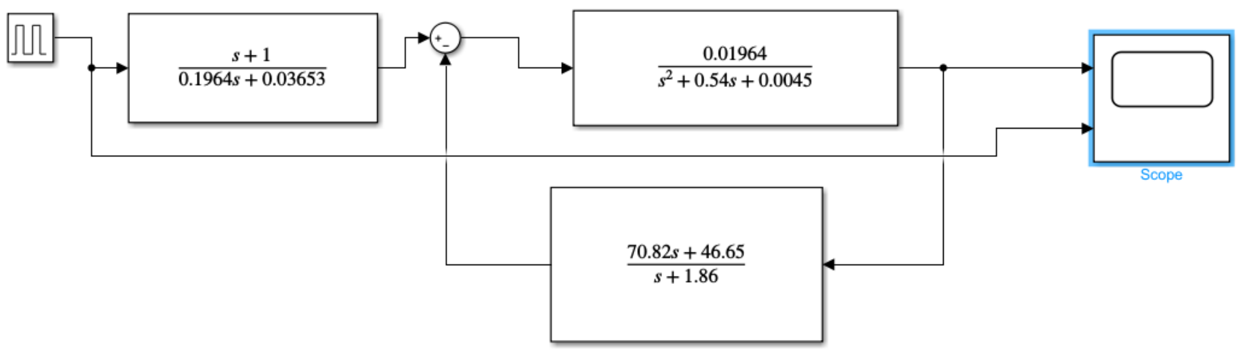

Figure 6: Simulink model of STR controller

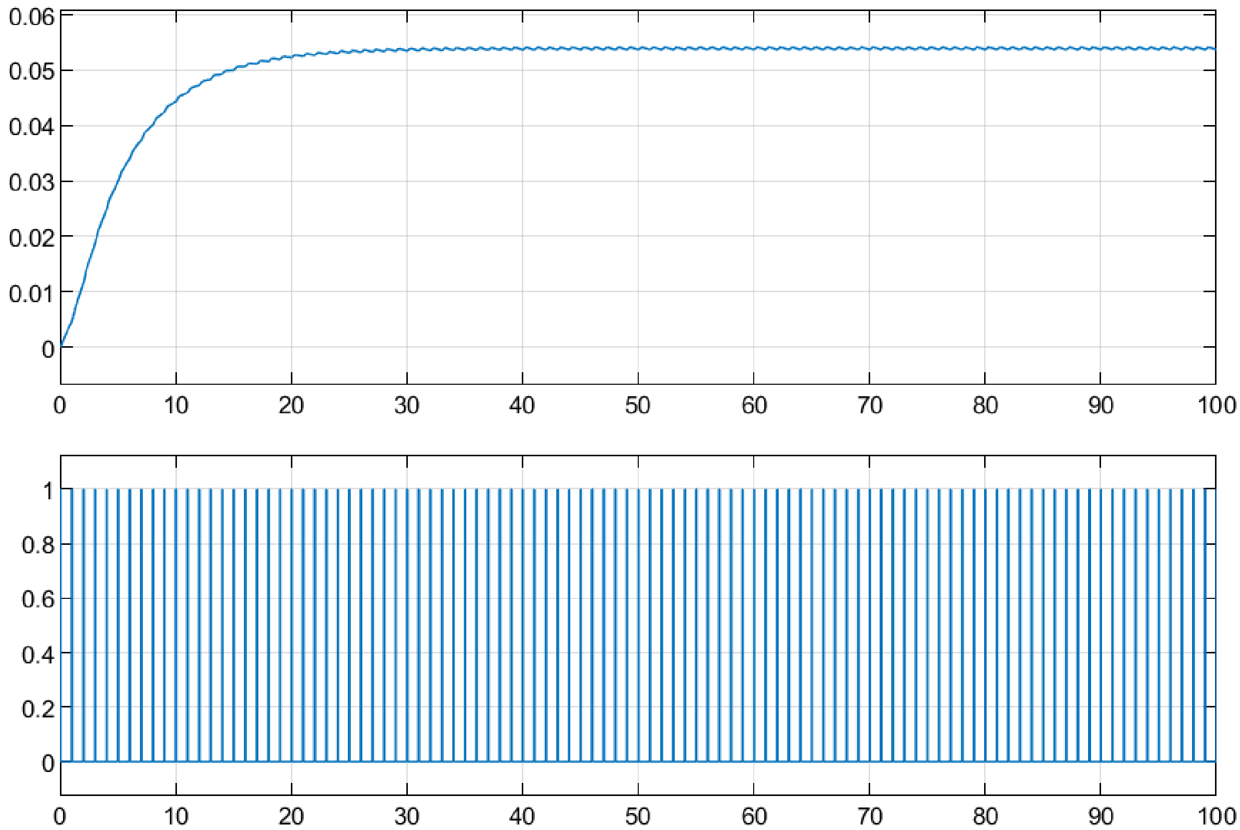

Figure 7: Response from STR controller

Validation of STR Controller:

For validation purpose, one can change the transfer function parameters and see the response whether it can adapt the controller or not.

Let's modified transfer function,

$$G(s) = \frac{0.01964}{s^2 + 0.0045}$$

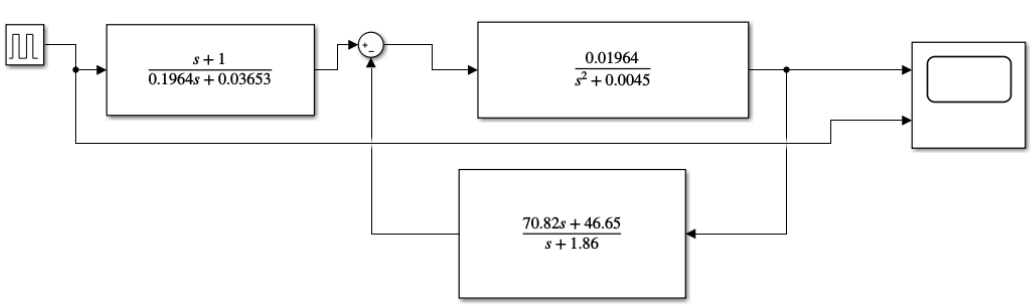

Figure 8: STR model with modified transfer function

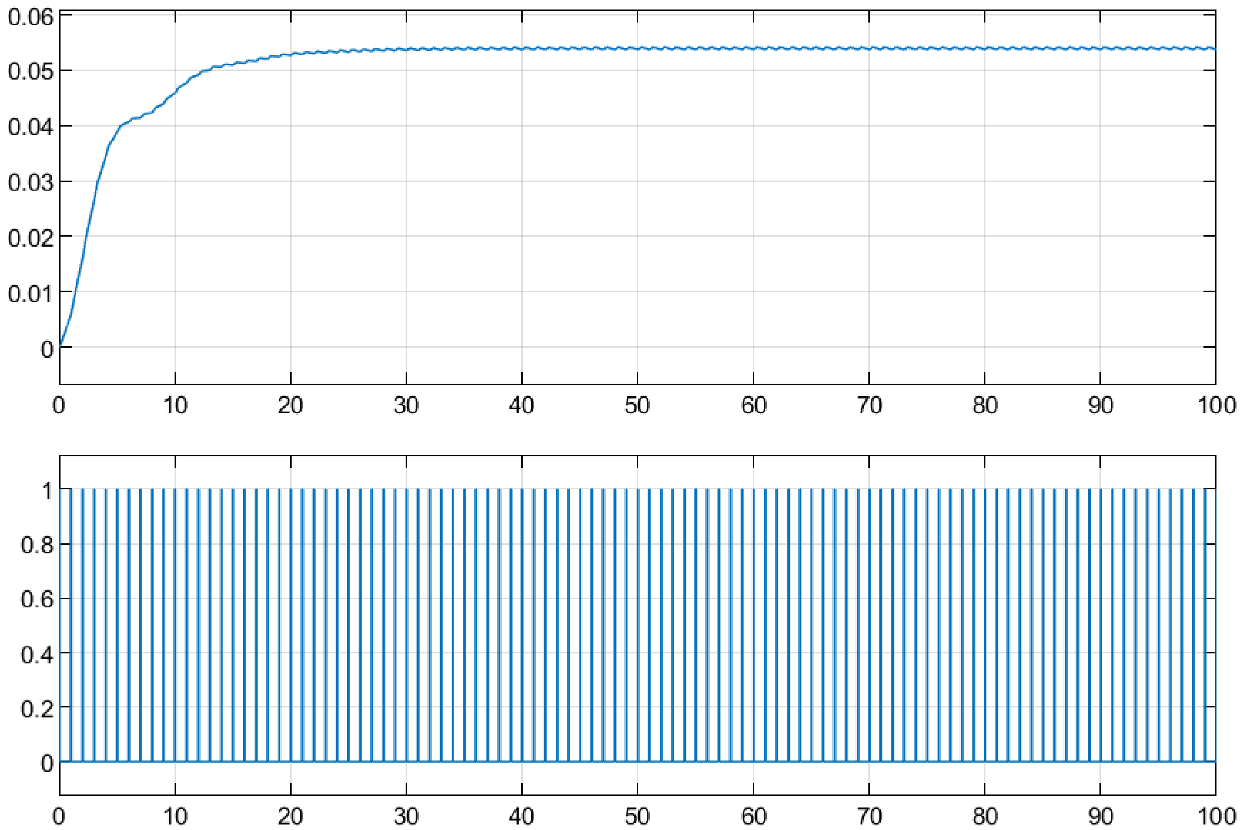

Figure 9: Simulation of STR using modified transfer function

From figure 8, it is clearly observed that no matter one change the parameter of the system, it is able to adapt with this controller.

Implementation of STR controller in MLS system:

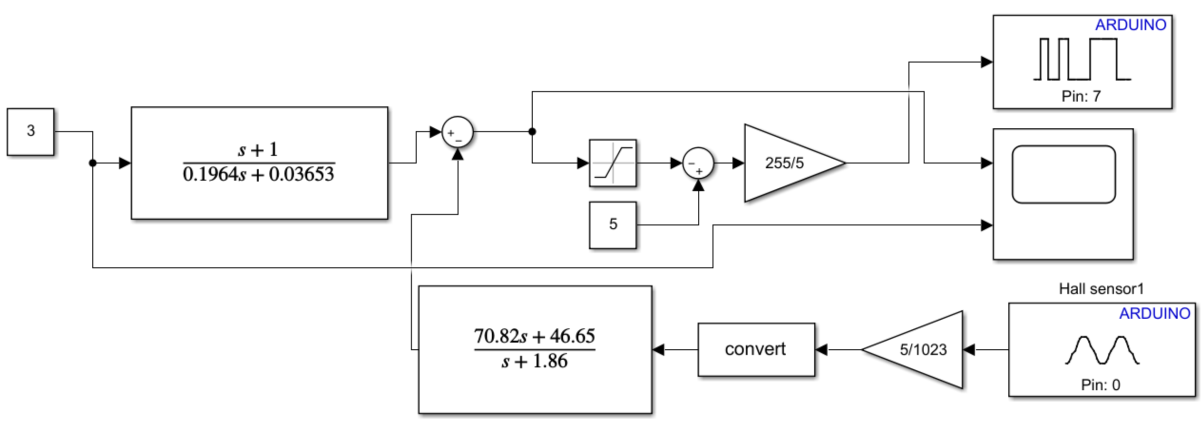

Figure 10: Implementation of PID controller to magnetic levitation system

Model Transfer function generation for MRAC controller:

For model reference controller designing, we need a model transfer function. For deriving this model transfer function, one can use PID controller output as a model reference. One can generate this transfer function using system identification toolbox in Matlab.

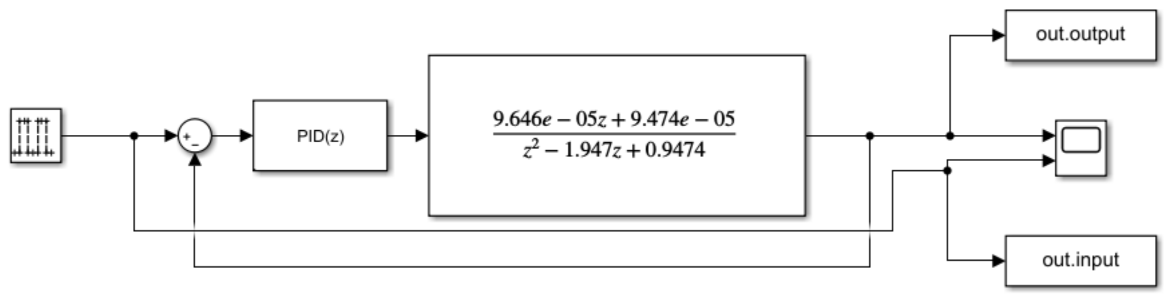

Figure 11: Simulink model of the model reference for MRAC controller

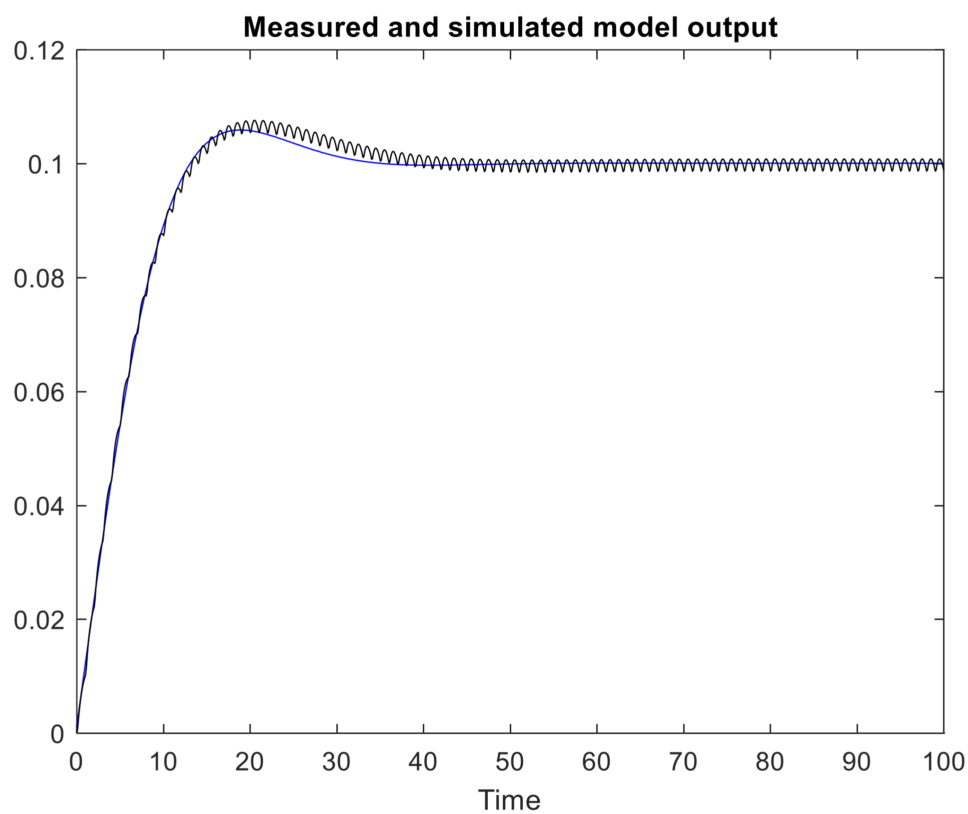

Figure 12: Validation from system identification

Model Reference Transfer function, $G_m(s) = \frac{0.009885}{s^3+0.5245s^2+0.105s+0.009876}$

Reference:

[1] “Magnetic Levitation.” [Online]. Available: http://www.zeltom.com/emls.html. [Accessed: 15-Feb-2020].

[2] H. I. Ali, "Robust PI-PD Controller Design for Magnetic Levitation System," Eng. and Tech. Journal , vol. 32, part (A), no. 3, 2014.

[3] F. Franquiz, A. Hurst, and Y. Tang, "Teaching Neural Network Control System Design Using a Low-Cost Rapid Control Prototyping Platform," ASME 2013 International Mechanical Engineering Congress and Exposition, 2013.

[4] T. T. Salim and V. M. Karsli, "Control of Single Axis Magnetic Levitation System Using Fuzzy Logic Control," Int. J. Advanced Computer Science and Applications, vol. 4, no. 11, pp. 83-88, 2013.

[5] M. G. Yoon, “A Simple Analog Controller for a Magnetic Levitation Kit,” vol. 5, no. 03, pp. 94–97, 2016.

[6] https://en.wikipedia.org/wiki/Magnetic_levitation