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IMPLEMENTATION OF NARMA-L2 CONTROLLER FOR MAGNETIC LEVITATION SYSTEM

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ABSTRACT

This paper presents the design of feedback linearization and neural network based feedback linearization (NARMA-L2) controller for a magnetic levitation system. The magnetic levitation system is one of the classical nonlinear systems. The paper provides simulation results to validate the theoretical design.

Keywords: Magnetic Levitation System, NARMA-L2 Controller

I INTRODUCTION

Most of the system in real world are nonlinear system. In control theory different classical nonlinear system are studied. One of the nonlinear system is magnetic levitation system. Magnetic Levitation is a method by which an object is suspended in the air with no support other than the magnetic field. However difficulty in stably levitating an object by using inverse square law is studied by Samuel Earnshaw in 1842. Earnshaw's Theorem states that a point charge cannot have stable equilibrium position when a static force is applied following the inverse square law. This theorem is also applicable to the magnetic force of the permanent magnet. Werner Braunbeck extended the analysis to uncharged dielectric bodies in electrostatic fields and magnetic bodies in magnetostatic fields in 1939 and also by Papas (1977). It was observed that for diamagnetic material, super conducting body and conducting body with eddy current induced on them can have stable equilibrium point.

Magnetic Levitation can be classified according to magnetism as Levitation by attraction and levitation by repulsion. Levitation by attraction works on the principle that when two magnets are placed end to end with opposite pole facing each other.

Levitation by repulsion works on the principle that when two magnets are place end to end with same pole facing each other. Magnetic Levitation can be classified according to principle by which levitation is made as

a) Levitation by repulsive force between magnets of fixed strengths

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b) Levitation by magnetic field on diamagnetic materials

c) Levitation by superconducting surface

d) Levitation by eddy current induced on conducting surface due to magnetic field

e) Levitation by force acting on current carrying conductor in magnetic field

f) Levitation by controlled DC or AC supply to electromagnetic coil by control algorithm

g) Mixed μ systems where μ system are materials where some place the permeability is less than 1 and in some place more than 1.

The objective of this paper is to design NARMA-L2 Controller for magnetic levitation system.

II LITERATURE REVIEW

This section provides a comprehensive literature review of different controllers used to control the maglev system. Nonlinear controller [1], Reinforced neural network controller [2], Output feedback control [3], Robust Control [4], Identification using ARX model [5], Nonlinear model predictive control [6], PID control [7,10], LQR-PID [8], Input-output feedback linearization [9], H-∞ control [11], Multi-rate ripple free dead-beat control [12], Adaptive control [13], Linear and nonlinear control [14], Adaptive output feedback control [15], Total sliding mode and PSO [16], Fuzzy sliding mode [17], Dynamic surface control [18], Adaptive backstepping [19].

III MATHEMATICAL MODEL

This section provides detailed analysis of magnetic levitation system.

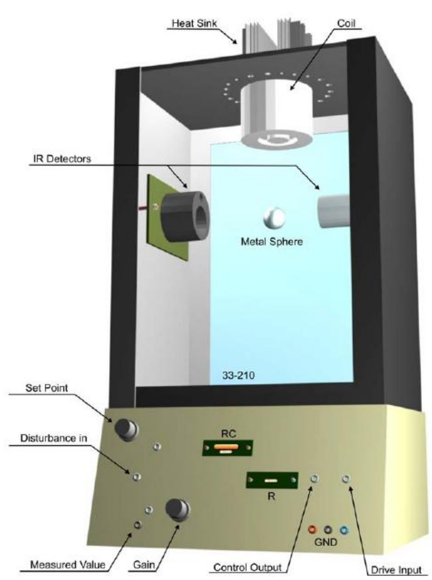

Fig. 1. Magnetic force created by magnetic field

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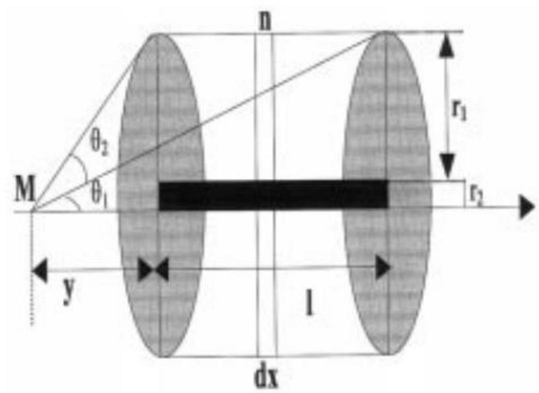

Fig. 2 represents the magnetic force created by magnetic field.

The dynamics of ferromagnetic ball can be given by

$$m\frac{d^2y(t)}{dt^2} = mg - F(t)$$

Here, m is the mass of the ball, g is gravitational acceleration and F is magnetic control force.

The electrical part of magnetic levitation system is represented by $E = RI + L\frac{dI}{dt}$

The magnetic force created by the magnetic field can be represented by $dB = \frac{\mu_o\mu_r I}{2r}\left(\left(\frac{x}{r}\right)^2 + 1\right)^{-1.5} ndx$

Here r is the radius, l is the length, I is current

Here, $y = r\cot(\theta)$

$$dB = \frac{\mu_o\mu_r nI}{2}\left(-\sin(\theta)\right)d\theta$$

$$B = \frac{\mu_o\mu_r nI}{2}\left(\cos(\theta_2) - \cos(\theta_1)\right)$$

$$\cos(\theta_2) = \frac{(y+l)}{\sqrt{(y+l)^2 + r^2}} \quad \cos(\theta_1) = \frac{(y)}{\sqrt{(y)^2 + r^2}}$$

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$$B=\frac{\mu_o\mu_r nI}{2}\left(\frac{y+l}{\sqrt{(y+l)^2+r^2}}-\frac{y}{\sqrt{y^2+r^2}}\right)$$

$$dB=\frac{\mu_o\mu_r nI}{2}\left(\frac{y+l}{\sqrt{(y+l)^2+r^2}}-\frac{y}{\sqrt{y^2+r^2}}\right)ndr$$

$$dB=\frac{\mu_o\mu_r n^2 I}{2}\left(\begin{array}{l}(y+l)\sin^{-1}\left(\frac{r_2}{y+l}\right)-\sin^{-1}\left(\frac{r_1}{y+l}\right)\\+y\left(\sin^{-1}\left(\frac{r_1}{y}\right)-\sin^{-1}\left(\frac{r_2}{y}\right)\right)\end{array}\right)$$

The magnetic force can be represented by $F=\frac{B}{2\mu_o}S$

$$F=CI^2\left(\begin{array}{l}(y+l)\sin^{-1}\left(\frac{r_2}{y+l}\right)-\sin^{-1}\left(\frac{r_1}{y+l}\right)\\+y\left(\sin^{-1}\left(\frac{r_1}{y}\right)-\sin^{-1}\left(\frac{r_2}{y}\right)\right)\end{array}\right)^2$$

$$C=\frac{\left(\mu_o\mu_r n^2\right)^2 S}{8\mu_o}$$

The state-space representation of system can be represented by $\begin{cases}\dot{x}=f(x)+g(x)u\\ y=h(x)=x_2\end{cases}$

where $f(x)=(f_1,f_2,f_3)^T=\begin{pmatrix}\frac{-Rx_1}{L}\\ x_3\\ g-\frac{1}{m}\left(\frac{x_1^2}{b_o+b_1x_2+b_2x_2^3+b_3x_2^4}\right)\end{pmatrix}$

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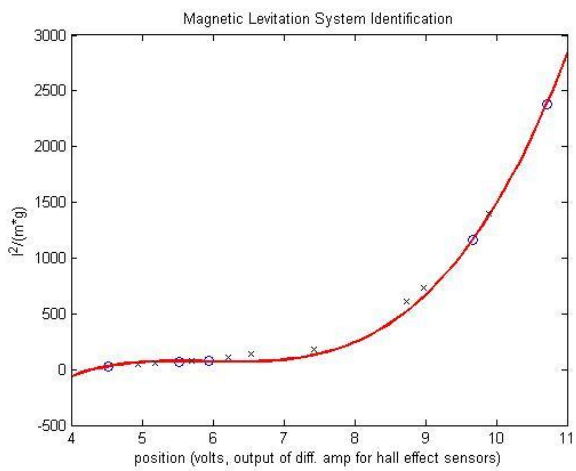
$$g(x)=\begin{pmatrix} \frac{1}{L} \\ 0 \\ 0 \end{pmatrix}$$

Fig. 3 shows the input-output curve-fitting data for magnetic levitation system.



IV FEEDBACK LINEARIZATION CONTROLLER

This section provides controller design for magnetic levitation system. Fig. 4 provides the block diagram of control system for magnetic levitation system.

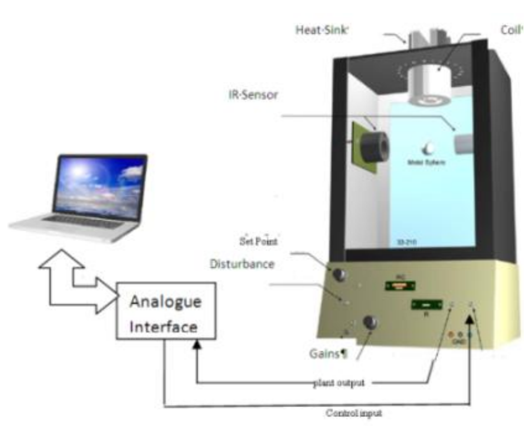


Fig 4 : System identification of magnetic levitation system

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Feedback linearization cancels the nonlinearities in a nonlinear system s.t. the closed-loop dynamics is in a linear form. be applied to a class of nonlinear systems. Lets consider a nonlinear system $\begin{cases} \dot{x} = f(x) + g(x)u \\ y = h(x) \end{cases}$

$x \in R^n$ is the state, u is the control input, y is the output. f, g are smooth vector fields on R^n. h is a smooth nonlinear function.

The Jacobian linearization of above nonlinear system can be represented as

$$\dot{x} = \left[\frac{\partial f(x_o)}{\partial x} + \frac{\partial g(x_o)}{\partial x}u_o\right](x - x_o) + g(x_o)(u - u_o)$$

$$y - y_o = \frac{\partial h(x_o)}{\partial x}(x - x_o)$$

The linearization is carried out at equilibrium point (u_o, x_o, y_o)

Differentiating y with respect to t we get,

$$\dot{y} = \frac{\partial h}{\partial x} f(x) + \frac{\partial h}{\partial x} g(x)u$$

$$\dot{y} = L_f h(x) + L_g h(x)u$$

$L_f h(x): R^n \to R$ $L_g h(x): R^n \to R$ are defined as Lie derivative of h with respect to f and g.

The state feedback law at equilibrium point $x = x_o$ can be defined as $u = \frac{1}{L_g h(x)}\left(-L_f h(x) + v\right)$

$$u = \frac{1}{L_g L_f^{\gamma-1} h(x)}\left(-L_f^{\gamma} h(x) + v\right)$$

V NARMA-L2 CONTROLLER

NARMA-L2 neural network controller proposed by K. S. Narendra and S. Mukhopadhyay is a neural network based approximate feedback linearization method, which has the same central idea as the exact feedback linearization, but requires far less computation.

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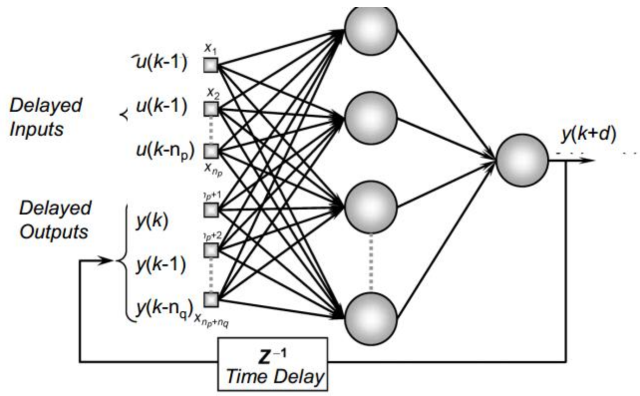

Fig 5 : Neural network system

A standard model structure is used for the process. The nonlinear model structure used in this paper is NARMA (nonlinear auto-regressive moving average). The discrete time NARMA model can be represented by

$$y(k+d)=N\left[y(k),y(k-1),\text{---},y(k-n+1),u(k),u(k-1),\text{---},u(k-n+1)\right]$$

Here $u(k)$ is the system input, $y(k)$ is the system output. $N(.)$ is the nonlinear function.

The desired trajectory can be represented as

$$y(k+d)=y_r(k+d)$$

The nonlinear controller can be represented as

$$u(k)=G\left[y(k),y(k-1),\text{---},y(k-n+1),y_r(k+d),u(k-1),\text{---},u(k-m+1)\right]$$

The controller based on NARMA-L2 model can be represented as

$$\hat{y}(k+d)=f\begin{pmatrix}y(k),y(k-1),\text{---},y(k-n+1),\\u(k-1),\text{---},u(k-m+1)\end{pmatrix}+g\begin{pmatrix}y(k),y(k-1),\text{---},y(k-n+1),\\u(k-1),\text{---},u(k-m+1)\end{pmatrix}u(k)$$

The NARMA-L2 based controller can be represented as

$$u(k+1)=\frac{y(k+d)-f\left(y(k),\text{---},y(k-n+1),u(k),\text{---},u(k-n+1)\right)}{g\left(y(k),\text{---},y(k-n+1),u(k),\text{---},u(k-n+1)\right)}$$

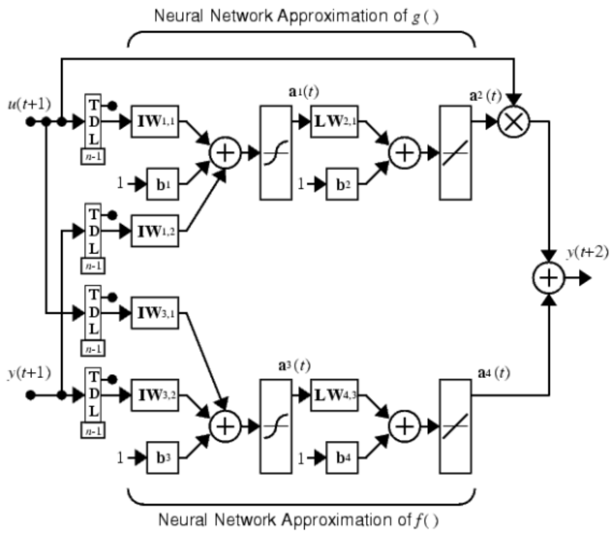

Fig 6 : Neural Network Approximation

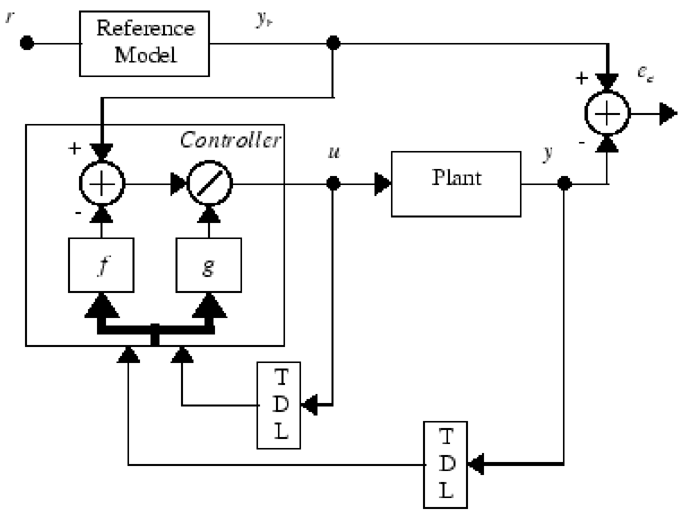

Fig 7 : NARMA-L2 controller

VI SIMULATION RESULTS

This section provides simulation results for NARMA-L2 controller for magnetic levitation system. The neural network setting for plant identification is shown in Fig. 8.

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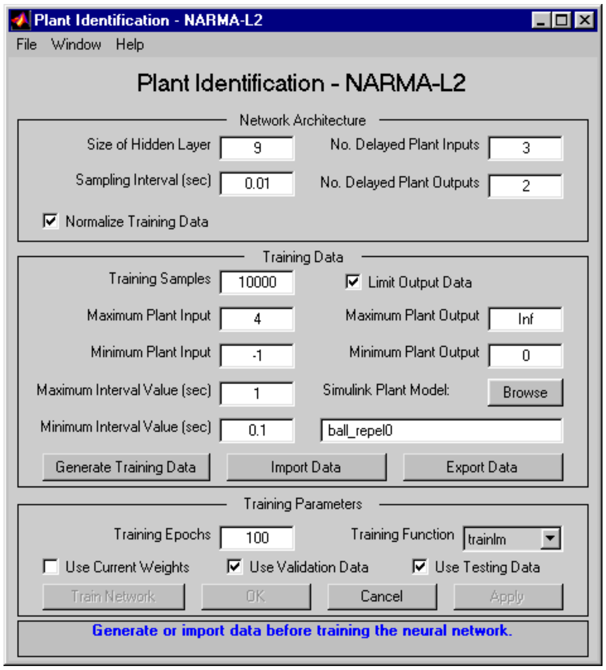

Fig 8 : Plant identification of maglev system using neural network

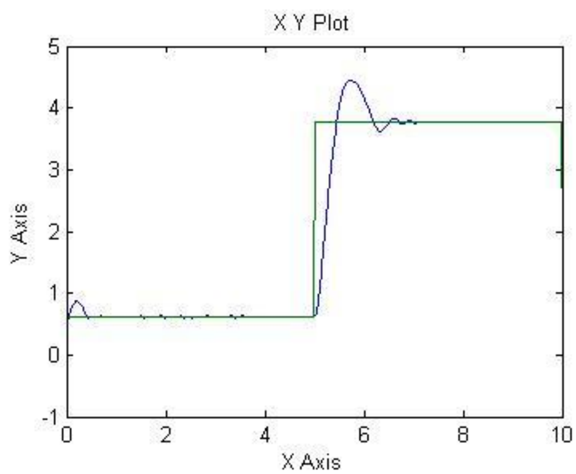

Fig. 9 shows the input-output response of maglev system using NARMA-L2 controller.

VII CONCLUSION

This paper provides the design of NARMA-L2 controller for magnetic levitation system. Detailed mathematical model of the system, design of feedback linearization controller and NARMA-L2 controller has been discussed in this paper. Simulation results have been provided in this paper.

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