

NONLINEAR FEEDBACK MODEL ATTITUDE CONTROL USING CCD
IN MAGNETIC SUSPENSION SYSTEM

CHIN E. LIN ANN-SAN HOU

INSTITUTE OF AERONAUTICS AND ASTRONAUTICS

CHENG KUNG UNIVERSITY
TAINAN, TAIWAN, CHINA

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ABSTRACT

A model attitude control system for a magnetic suspension system using CCD camera is studied in this paper. In a recent work, a position and attitude sensing method was proposed using CCD [1]. From this result, model position and attitude in a magnetic suspension system can be detected by generating digital outputs. Based on this achievement, a control system design using nonlinear feedback technique for magnetic suspended model attitude control is proposed.

THE PROPOSED METHOD

In the CCD sensing system, positions of specified points on the model are detected, x_1 and x_2 . The pitch angle, θ , and its $\sec(\theta)$ are calculated by hardware circuit. Assuming that two magnetic coils are used in such a system to levitate and control the magnetic suspended model in the test area, the control circuit then generates voltage outputs for magnet coils to induce appropriate currents. A studied magnetic suspension system as shown in Fig. 1 includes two controlled magnets with a longitudinal model. The proposed system block diagram is shown in Fig. 2.

Referring to the magnetic suspended model in Fig. 1, the energy equations of the model are described as:

the kinetic energy:

$$T = \left(\frac{m}{2}\right) [(\dot{X}_1 + \dot{X}_2)/2]^2 + \left(\frac{1}{24}m l^2\right) \dot{\theta}^2 \quad (1)$$

the potential energy:

$$V = -[(X_1 + X_2)/2] m g \quad (2)$$

where x_1 and x_2 are positions of the specified points on the model, θ is the pitch angle of the model, m is the model mass on the center of gravity, l is the effective distance between two specified points on the model, and g is the gravitational acceleration, with a constraint equation of:

$$\sin(\theta) = (X_2 - X_1) / l \quad (3)$$

From the Lagrange equation, we have:

$$\frac{d}{dt}(\partial L / \partial \dot{X}_1) - (\partial L / \partial X_1) = -F_1 + \lambda$$

to get:

$$\left(\frac{m}{4}\right) (\ddot{X}_1 + \ddot{X}_2) - mg/2 = -F_1 + \lambda \quad (4)$$

for variable x_1 ; then

$$\frac{d}{dt}(\partial L / \partial \dot{X}_2) - (\partial L / \partial X_2) = -F_2 - \lambda$$

to get:

$$\left(\frac{m}{4}\right) (\ddot{X}_1 + \ddot{X}_2) - mg/2 = -F_2 - \lambda \quad (5)$$

for variable x_2 ; and

$$\frac{d}{dt}(\partial L / \partial \dot{\theta}) - (\partial L / \partial \theta) = l \cos(\theta) \lambda$$

to get:

$$(m l^2 / 12) \ddot{\theta} = l \cos(\theta) \lambda \quad (6)$$

for variable θ , where F_1 and F_2 represent the magnetic forces to the model, λ and $l \cos(\theta)\lambda$ represent the constraint forces.

Subtracting Eq. 4 from Eq. 5,

$$\lambda = (F_1 - F_2) / 2$$

and substituting into Eq. 6, we get:

$$(m l^2 / 12) \ddot{\theta} + [(F_2 - F_1) / 2] l \cos(\theta) = 0 \quad (7)$$

Summing Eq. 4 and Eq.5, we get:

$$m (\ddot{X}_1 + \ddot{X}_2) / 2 - m g = -(F_1 + F_2) \quad (8)$$

Using the nonlinear feedback technology, let the relations of applied magnetic forces and feedback signals be:

$$F_2 - F_1 = (-k_0 + k_1\theta + k_2\dot{\theta}) \sec(\theta) \quad (9)$$

$$F_2 + F_1 = C_0 - C_1(X_1 + X_2) - C_2(\dot{X}_1 + \dot{X}_2) \quad (10)$$

where k_i 's and C_i 's are system constants.
Substitute Eq. 9 into Eq. 7 to get:

$$(m l^2 / 12) \ddot{\theta} + (l / 2) (-k_0 + k_1\theta + k_2\dot{\theta}) = 0 \quad (11)$$

and Eq. 10 into Eq. 8 to get:

$$(m / 2) (\ddot{X}_1 + \ddot{X}_2) + C_1 (X_1 + X_2) + C_2 (\dot{X}_1 + \dot{X}_2) = mg + C_0 \quad (12)$$

From Eq. 11 and Eq. 12, the external forces F_1 , F_2 , pitch angle θ and model position at its center of gravity $(x_1+x_2)/2$ can be steadily controlled to a stable condition.

Summing Eq. 9 and Eq. 10, we get:

$$F_1 = [(-k_0 + k_1\theta + k_2\dot{\theta}) \sec(\theta) + C_0 - C_1(X_1 + X_2) - C_2(\dot{X}_1 + \dot{X}_2)] / 2 \quad (13)$$

$$F_2 = [-(-k_0 + k_1\theta + k_2\dot{\theta}) \sec(\theta) + C_0 - C_1(X_1 + X_2) - C_2(\dot{X}_1 + \dot{X}_2)] / 2 \quad (14)$$

From a known magnetic force model of the relationship between magnetic force and coil current in quadratic forms,

$$F_1 = (M_1 + C(i_1)i_1^2) / P(x_1, y_1) \quad (15)$$

$$F_2 = (M_2 + C(i_2)i_2^2) / P(x_2, y_2) \quad (16)$$

where M_1 and M_2 are magnetic dipoles. $P(x, y)$'s are polynomial functions of x and y . $C(i)$ is constant dependent on control current i .

The magnetic coil currents can be obtained as:

$$i_1 = [F_1 P(x_1, y_1) - M_1]^{1/2} \quad (17)$$

$$i_2 = [F_2 P(x_2, y_2) - M_2]^{1/2} \quad (18)$$

The control parameters of magnetic coil current can be calculated and controlled.

In this paper, the control system which feedbacks position signals from CCD camera and then generates appropriate output currents to the magnetic suspension system is designed and implemented using hardware circuits. System description and experimental results are demonstrated in a two coil magnetic suspension system.

SYSTEM IMPLEMENTATION

For the implementation of the proposed method, the block diagram shown in Figure 2 is designed and fabricated into hardware circuits. In the design process, the output data of the position and attitude are generated as shown in Figure 3. The input data of Figure 3 are generated from the proposed CCD measurement system [1]. The detailed block diagram of the real time control system for position and attitude control of the suspended model through CCD is designed as shown in Figure 4. Before applying the control method to the proposed system as shown in Figure 1, system model and parameters should be obtained. The system parameter measurement is carried out via magnetic field and force measurement from different locations within the control range of the two-pole levitation system. Assume that x denotes the vertical suspending distance from the pole, and y denotes the horizontal shift distance between two poles. The parameter measurement process sets the locations of y at 0 mm, 8 mm, and 16 mm for magnetic coil currents of 1.0 A to 5.0 A with 0.5 A each step. The magnetic force in g is measured and plotted on to figures similar to Figure 5. By a curve fitting process, the constant C with respect to coil current i is measured to get Figure 6. Via the described procedures, the polynomial function $P(x,y)$ as defined previously can be fitted into a figure as shown in Figure 7 with respect to different values of y . The data of $P(x,y)$ is used to substitute into Eqs. 15 and 16 to calculate the required magnetic force from each electromagnet pole. In the implementation, the applied power supply voltage V_{c1} and V_{c2} should be determined. From circuit designs, the relationship of voltage to current is fixed: $V_{c1} = i_1/2$, and $V_{c2} = i_2/2$, respectively. In the control concept, a ROM-mapping method is used. The basic idea of ROM-mapping is to memorize all possible positions and attitude control data into the read-only memory (ROM). The corresponding control data of power voltage will be searched from the ROM, and sent out as control commands.

PRELIMINARY RESULTS

In this study, the magnetic suspended model control is accomplished by CCD cameras. From the position and attitude sensing [1], two CCD's are proposed for six degrees of freedom measurements, such as Z_c , X_c , and θ_{pitch} for CCD#1, and $Y_c, \theta_{roll}, \theta_{yaw}$ for CCD#2. The control approach can also follow the previous results. Some control results will be demonstrated in the conference. More details will be prepared on a revised version of the paper, and will be published in the conference proceedings. In this paper, the control system which feedbacks position signals from CCD camera and then generates appropriate output currents to the magnetic suspension system is designed and implemented using hardware circuits. System description and experimental results are demonstrated in a two coil magnetic suspension system.

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- [2] C. E. Lin, H. L. Jou, "Force Model Identification for Magnetic Suspension System via Magnetic Field Measurement", IEEE Transaction on Instrumentation and Measurement, June 1993, accepted.

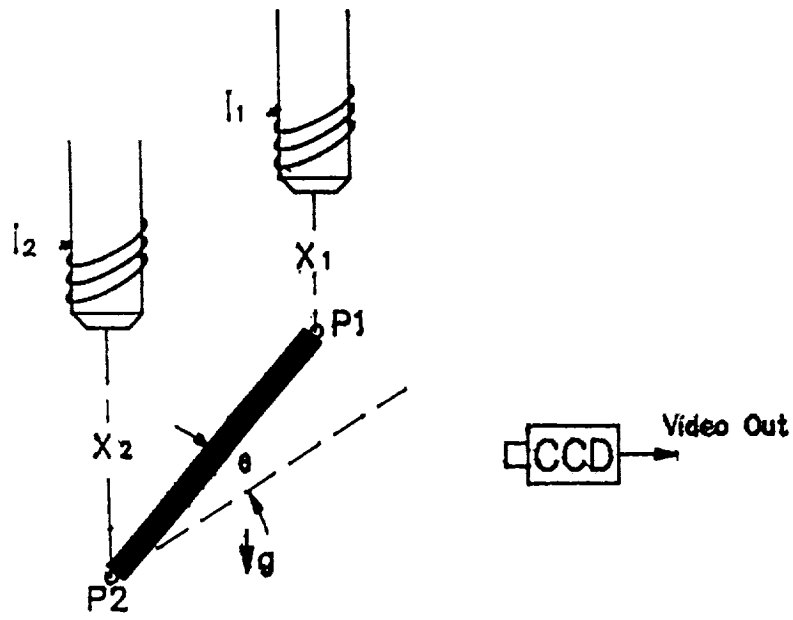


Fig. 1. The proposed experimental system using two electromagnet poles.

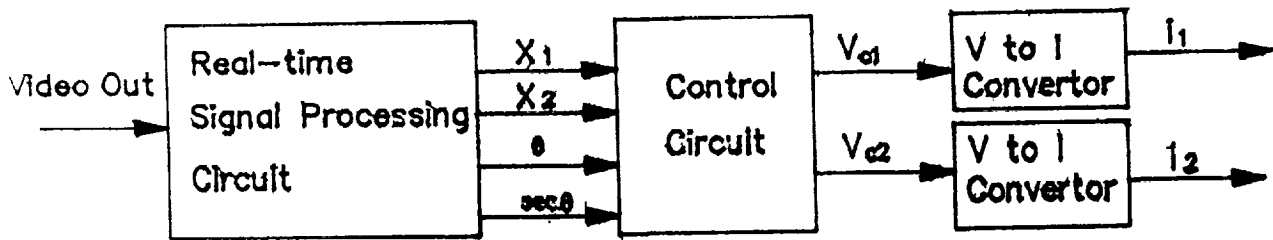


Fig. 2. The block diagram of real time position and attitude control from CCD measurement.

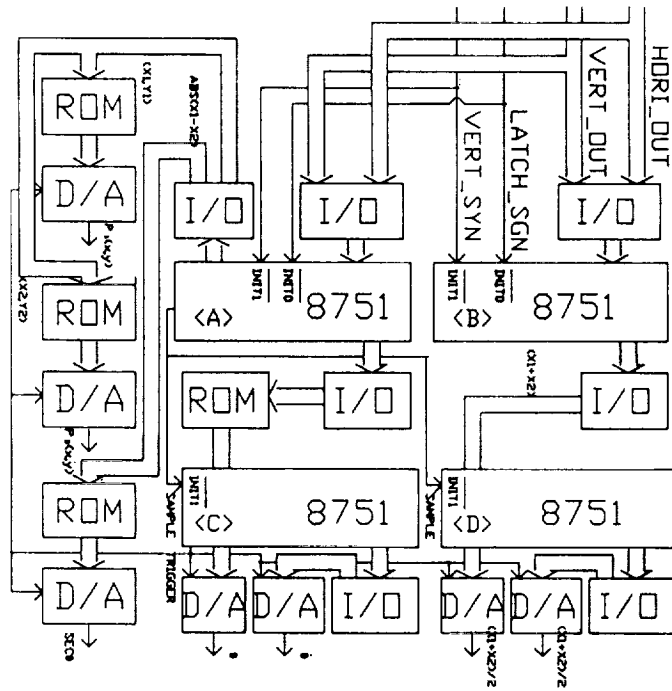


Fig. 3. The designed circuit in block diagrams to generate $\theta, \sec \theta$ and $(X_1 + X_2/2)$.

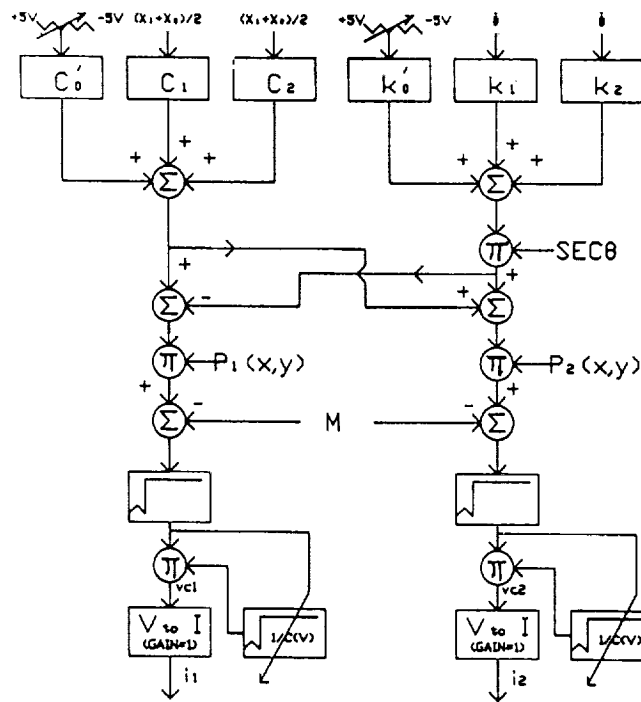


Fig. 4. The designed circuit in block diagrams to implement control algorithm .

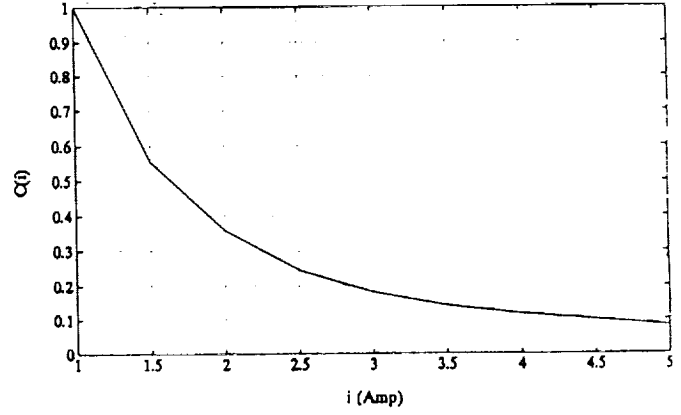
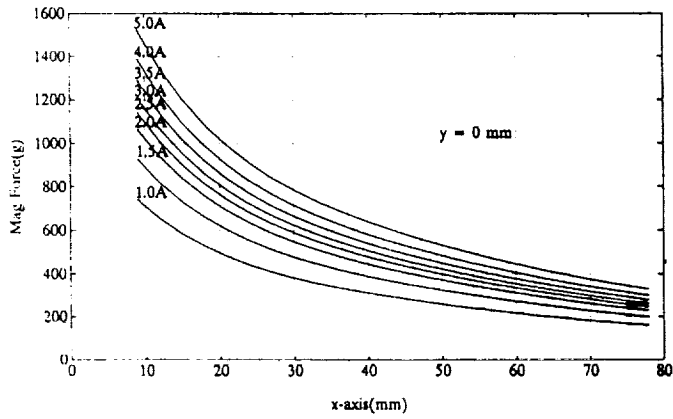


Fig. 6. Curve fitting result of constant C.

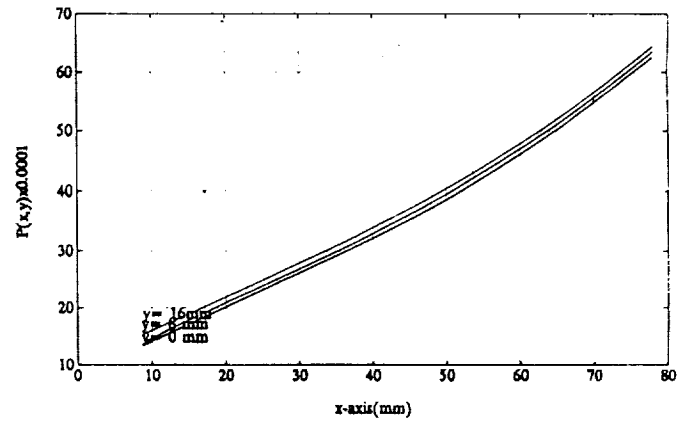
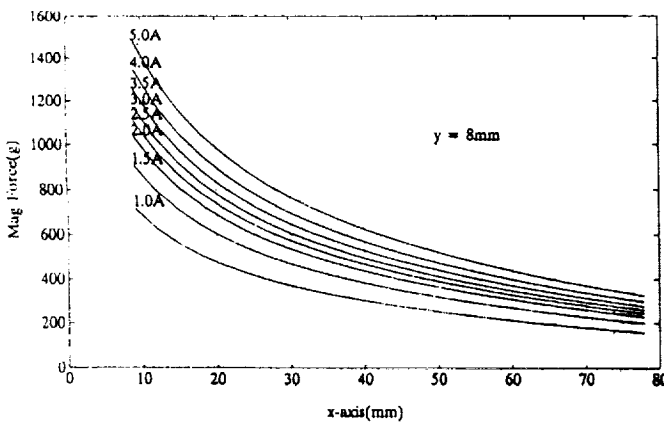


Fig. 7. The polynomial of $P(x,y)$ obtained from results of Fig. 5.

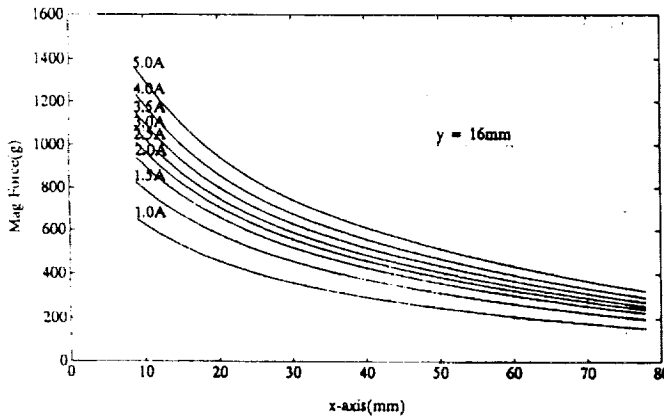


Fig. 5. Magnetic force measurement with respect to different coil currents.