Soft Sensing Modeling of Magnetic Suspension Rotor Displacements Based on Continuous Hidden Markov Model

Hao Gu, Huangqiu Zhu, and Yizhou Hua

School of Electrical and Information Engineering, Jiangsu University, Zhenjiang 212013, Jiangsu, China

Number: Mon-Af-Po1.05-13 [82]

Poster Session:1.05 13:15 - 15:00

Posters Area :Magnetic Levitation and Bearings

Background

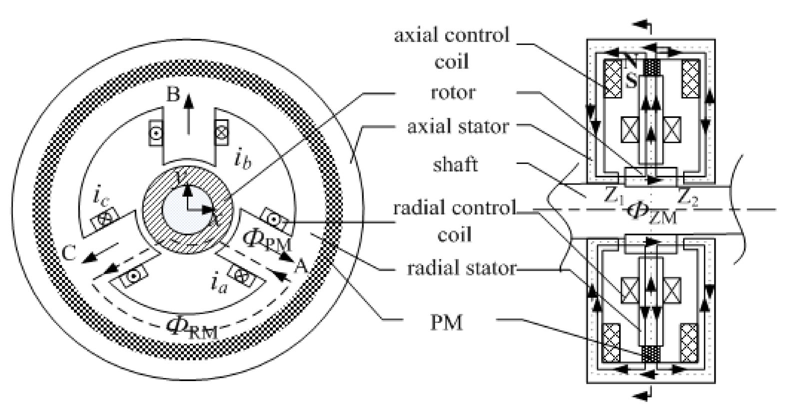
Magnetic bearings are a kind of bearings with high performance which can be suspended without mechanical contact by magnetic force. In traditional magnetic bearing system, displacement sensors are used to detect rotor position, which increases size and cost and weakens dynamic performance. High speed and high precision occasions call for new methods with higher accuracy and lower cost . However, there are more or less problems in the existing methods raised recently such as over-dependence on experience or mathematical models and requiring external circuits and special signal processing technologies. Soft sensing model can handle these problems well.

Objectives

- Modeling
- Collecting data and train continuous hidden Markov models
- Simulation

Working Principle of the 3-DOF-HMB

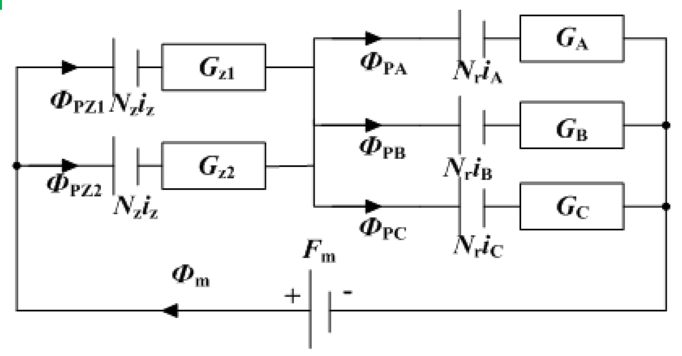
Structure and magnetic circuit of the 3-DOF-HMB



- The distribution of the bias flux generated by the permanent magnet is shown as the solid line in the right half. The bias flux starts from N pole of the PM, splits into two roads and goes into the radial stator through the radial air gap, and finally returns back to S pole.
- The distribution of the axial control flux is shown as the dotted line in the axial stator in the right half. The loop path is formed within the axial stator, the axial air gap and the rotor.
- Also in the right half, the distribution of the radial control flux is shown as the dotted line in the radial stator. When three-phase AC is injected into the control windings, according to the principle that the magnetic circuit goes follow the path with minimum reluctance, the flux flows successively through the radial stator, the radial air gap and the rotor, forming the radial control flux.

Mathematic Model of the 3-DOF-HMB

Equivalent magnetic circuit



- Ignore the effects of the eddy currents and the leakage;
- Ignore the effects of hysteresis;

On the basis of the hypotheses above, the whole magnetic circuit can be simplified as a system consisting of a leakage magnetic resistance and an effective magnetic circuit. According to the equivalent magnetic circuit method, the equivalent magnetic circuit can be obtained.

$$F_x = \frac{\sqrt{3}G_A^2(N_r i_A + \alpha F_m)^2}{4\mu_0 S_r} - \frac{\sqrt{3}G_C^2(N_r i_C + \alpha F_m)^2}{4\mu_0 S_r}$$

$$F_y = \frac{G_B^2(N_r i_B + \alpha F_m)^2}{2\mu_0 S_r} - \frac{G_A^2(N_r i_A + \alpha F_m)^2}{4\mu_0 S_r} - \frac{G_C^2(N_r i_C + \alpha F_m)^2}{4\mu_0 S_r}$$

$$F_z = \frac{G_{z_1}^2[N_z i_z + (1-\alpha)F_m]^2}{2\mu_0 S_z} - \frac{G_{z_2}^2[N_z i_z - (1-\alpha)F_m]^2}{2\mu_0 S_z}$$

$$\alpha = \frac{(G_{z1} + G_{z2})}{G_A + G_B + G_C + G_{z1} + G_{z2}}$$

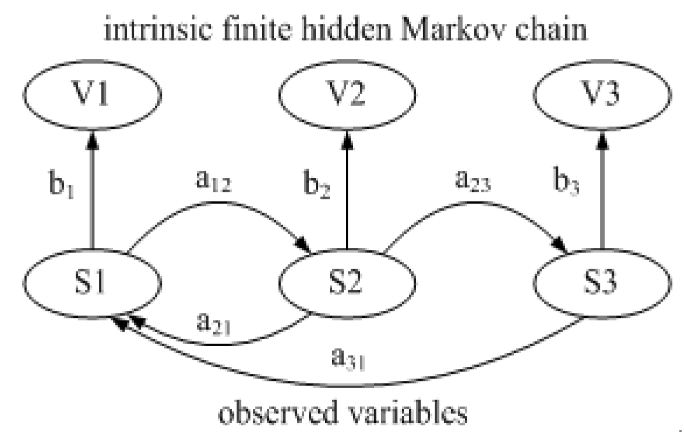
$$\begin{bmatrix} i_A \\ i_B \\ i_C \end{bmatrix} = \frac{1}{\sqrt{6}} \begin{bmatrix} \sqrt{3} & -1 \\ 0 & 2 \\ -\sqrt{3} & 1 \end{bmatrix} \begin{bmatrix} i_x \\ i_y \end{bmatrix}$$

$$\begin{cases} m\ddot{x} = F_x \\ m\ddot{y} = F_y \\ m\ddot{z} = F_z \end{cases}$$

The mathematical model is built by Equations above and sample data for CHMM modeling can be acquired by simulation sampling according to this model

Basic Introduction of CHMM

A CHMM with 3 states

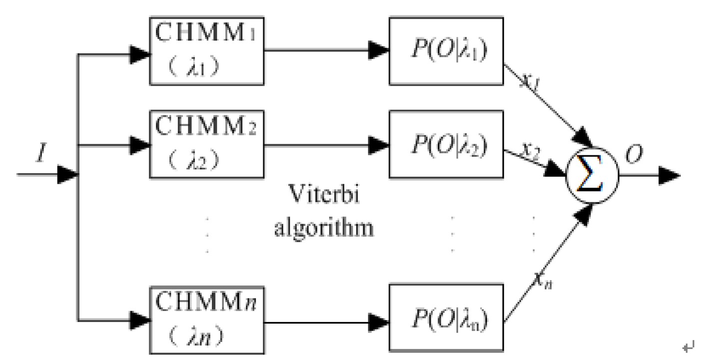


CHMM is a kind of model that describes undetected signals by probability statistics. It is consist of an intrinsic finite hidden Markov chain and observed variables associated with each state in the Markov chain. These two parts describe signals together and the former one is relayed on the later one.

Usually, a CHMM can be expressed by three parameters: λ= [A, B, Π], in which A represents state-transition probability matrix; B represents observation-output probability matrix; Π represents initial state distribution matrix

Steps of CHMM modeling

Prediction Steps



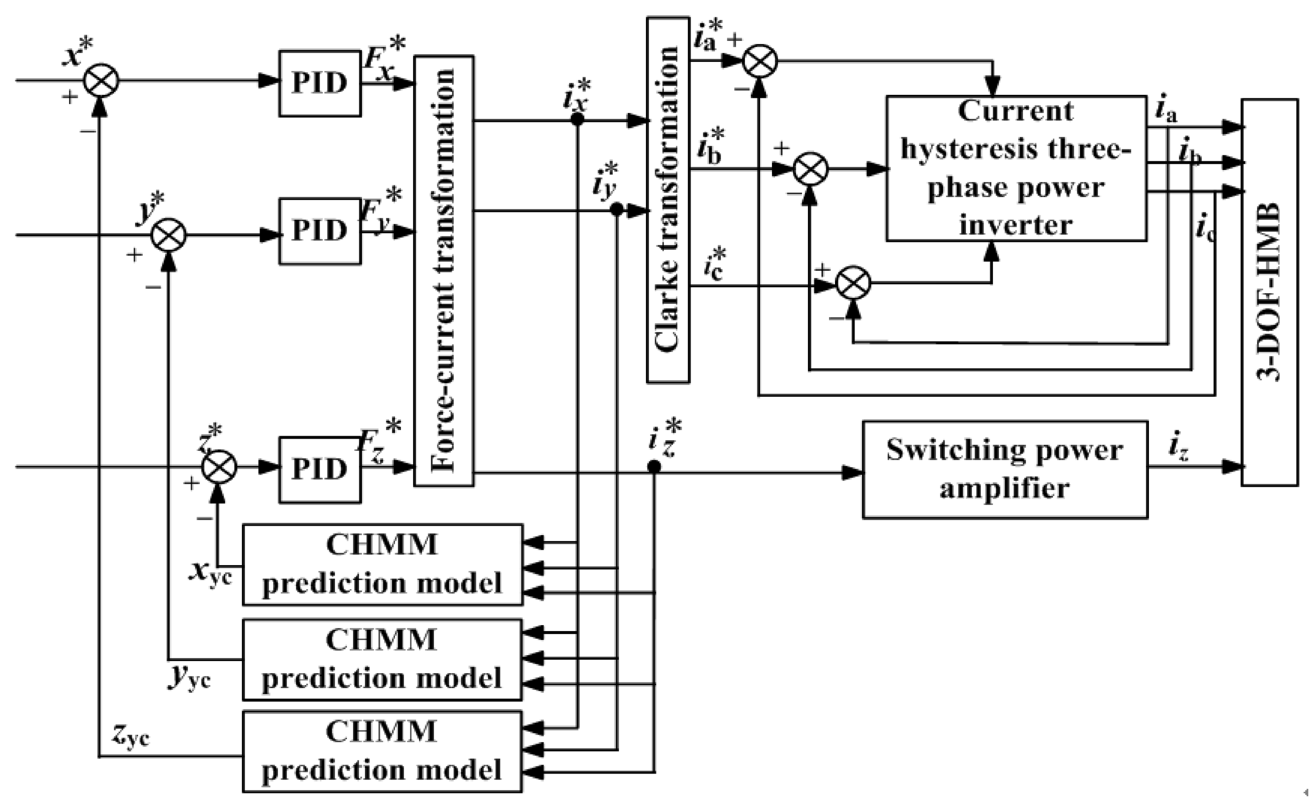
The key of the process above is to model CHMMs. The modeling steps are as shown on the right.

Modeling Steps

- Choose parameters
- Establish sample database
- Process the collected data
- Predicting the displacement

Simulations

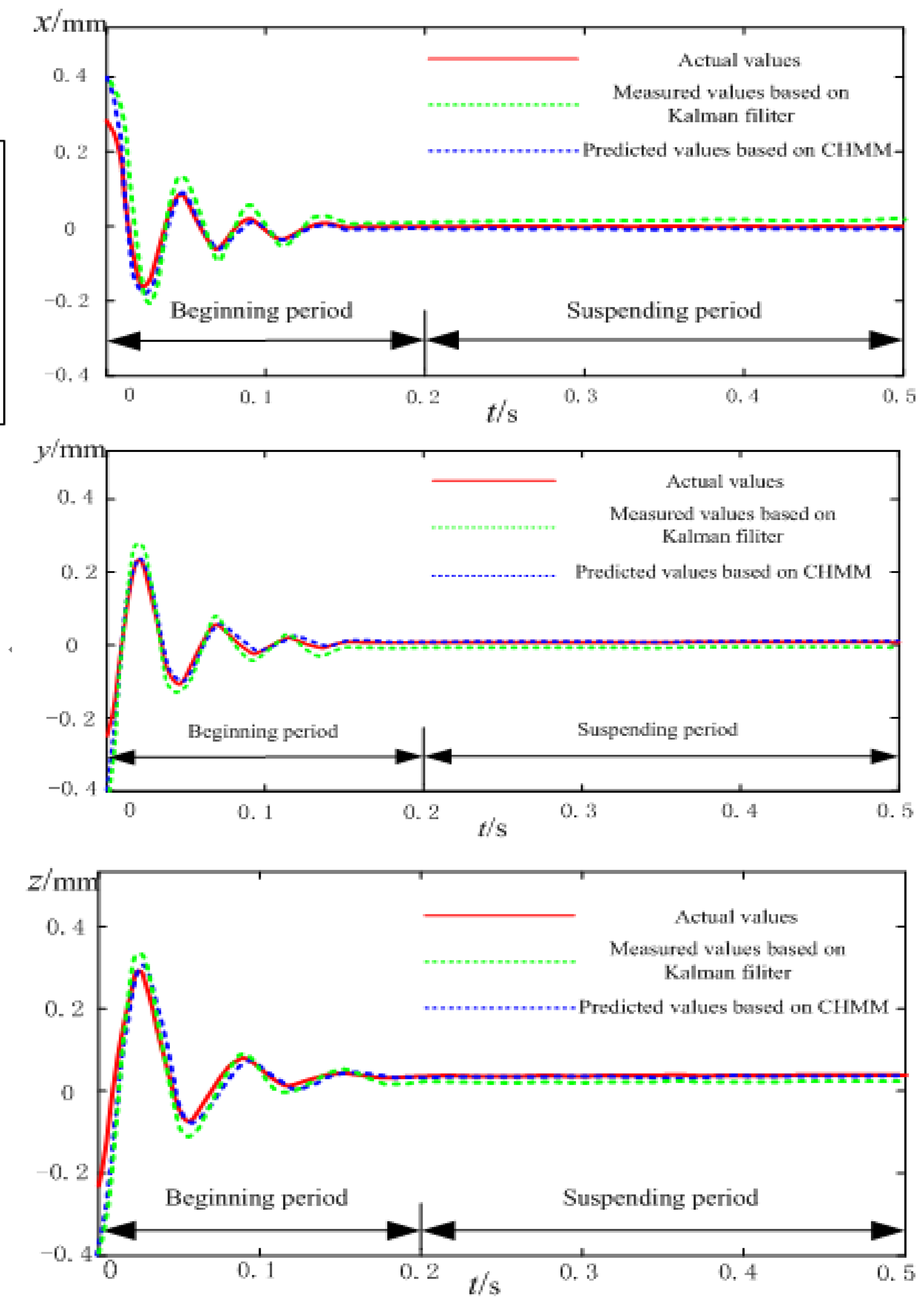
Frame diagram of the magnetic bearing system based on CHMM



COMPARISON OF MSE VALUES BETWEEN TWO PREDICTION MODELS

		Kalman filter /10⁻³	CHMM /10⁻³
X	Beginning period /μm	4.375	2.175
	suspending period / μm	2.5628	0.55
Y	Beginning period /μm	5.1625	2.627
	suspending period / μm	2.2477	0.471
Z	Beginning period /μm	4.726	2.373
	suspending period / μm	2.366	0.525

Actual values and detected values in three degrees



In order to quantify the error, mean square error values (MSE) are calculated, and the results are as shown in the table above. Take direction x as a example, it can be seen that in the beginning period, although the MSE value of the CHMM method is larger than that in the suspending period, it is still 36.57 percent smaller than the Kalman filter method. In the suspending period, the MSE value of the CHMM method is 17.13 percent smaller than the other method.

Conclusions

- ✓ The established mathematical model can effectively represent the nonlinear coupling characteristic of the 3-DOF-HMB. As a result, accurate and effective samples can be provided for modeling based on CHMM.
- ✓ The new self-sensing method raised in this paper is able to give a good prediction result in real time. Compared to other self-sensing method, CHMM has higher prediction accuracy and better stability