Design of TS-PDC type Fuzzy Controller and stabilization of Magnetic Levitation System

Amit Kaushal*, Dr. R. Mitra**
*Department of Electronics and Communication Engineering, Indian Institute of Technology, Roorkee, India
** Department of Electronics and Communication Engineering, Indian Institute of Technology, Roorkee, India

ABSTRACT
In this paper technique applies is known as parallel distributed compensation (PDC). This PDC technique is used for the position control of a Magnetic Levitation system. Parallel Distributed Compensation technique is based on the TS-PDC type fuzzy model. In this paper it is shown that this PDC technique can be successfully used for the stabilization of Magnetic Levitation System at any arbitrary chosen operating points of the system. Results are taken with the help of MATLAB and all the results are authenticated with the computer simulation of the nonlinear model of the Magnetic Levitation system. The TS type Fuzzy PDC controller has a wide range of the control system.

Keywords: Cerebellar model articulation controller, Fixed Quantization Variable Generalization CMAC, Fixed Generalization Variable Quantization CMAC.

I. INTRODUCTION
Magnetic Levitation System or in short name Maglev is very usable control system. In MLS, it is method of suspending the ball without any mechanical support. To accomplish this task, principle of electromagnetic induction is used. Maglev has the vast application in control system like as magnetic high speed passenger trains, low friction ball bearings, suspension wind tunnel models. Maglev can be categorized as attractive or repulsive systems and this system is based on the source of the levitate forces. These types system is highly nonlinear and normally unstable system.

These systems typically function as open or transitory loops and are well-defined through complex differential equations. The complexity of these differential equations shows the difficulty of handling these systems. Therefore designing a controller to choose the exact location of the magnetic levitation is significant and complex task [1, 2].

Here we deal with the application of TS type fuzzy PDC controller to nonlinear systems. It is well known fact, that in the control of real time systems, the instrumentation elements like instrumentation amplifier, sensors, digital to analog converter, analog to digital convertors etc. introduces some sort of unpredictable values in the information that has been collected. So, the controllers designed under idealized conditions tend to behave in an inappropriate. Since, uncertainty is inherent in the design of controllers for real world applications presenting how to deal with this problem using TS type fuzzy PDC controller, to reduce the imprecise information.

II. MATHEMATICAL MODEL OF THE SYSTEM
The electromagnetic suspension system we are studying is open loop stable and thus requires a feedback path along with a suitable controller for stable operation. The main challenge in controlling the position of the suspended object is to maintain the balance of the weight of the suspended object and the electromagnetic force acting on it. In our study we are only interested only in controlling the vertical position of the suspended object. Thus all the dynamics discussed here on will be concerned to vertical motion of the suspended object. Back ground material of the modelling of the plant is taken from [11].

Assuming the ball is not disturbed by external forces, the dynamic equation in vertical direction can be described as [10],

\[ m\ddot{x} = mg - F \] (1)

In equation (2.4.4.1), F is force due to magnetic field,

\[ F = k(i/x)^2 \] (2)

Then,

\[ m\ddot{x} = mg - k(i/x)^2 \] (3)

Where,

- Magnetic Field Constant \( k = -0.25\mu_0AN^2K_F \)
- ‘m’ is mass of ball,
- ‘g’ is acceleration due to gravity,
- ‘i’ is the current through the coil,
- ‘N’ is no. of turns in the coil,
- ‘A’ is the cross sectional area of the coil, and
- ‘x’ is the position of the ball levitating in the air.

In eq. (3), let us assume the state parameters \( x_1 \) and \( x_2 \) as,

\[ x_1 = x \] (4)
\[ x_2 = \dot{x} \]  
Hence, the state equations will be,
\[ \dot{x}_1 = x_2 \]  
\[ \dot{x}_2 = g - \frac{k}{m} (i/x_1)^2 \]  

III. PARALLEL DISTRIBUTED D COMPENSATION CONTROLLER

In the beginning, we represent the given nonlinear plant of maglev with the help of TS fuzzy model. TS type Fuzzy Controller is proposed new framework in the designing of Fuzzy Controller for nonlinear plant. A custom membership functions are designed which are based on the parameters of the magnetic levitation system. The simulation results of the Magnetic Levitation system show that the performance of T-S fuzzy model is much better than conventional T-S Fuzzy controller. Here we take the rule consequences of TS controller as:

IF \( z_1 \) is \( M_1 \) and and\( z_p \) is \( M_p \)
THEN \( \ddot{x}(t) = A_i x(t) + B_i u(t) \)
Where \( i=1,2,3 \ldots n \) the number of inference rules, \( M_i \) (\( i=1,2, \ldots n \); \( j=1,2, \ldots m \)) represents the input fuzzy sets. \( x(t) = [x_1(t), x_2(t) \ldots \ldots \ldots \ldots x(l)]^T \) \( R^l \) represents the state vector of the given system. \( u(t) \) represents the control input which have to be controlled. \( z(t) = [z_1, z_2 \ldots \ldots \ldots \ldots z_2] \in R^m \) represent the premise variable vector of fuzzy controller. \( A_i, B_i \) denotes the ith model parameters of the fuzzy system.

Parallel Distributed Compensation theory (PDC) is the compensation for each fuzzy model rule. The resulting overall fuzzy controller, which is nonlinear in general, is a fuzzy combination of each individual linear controller shares the same fuzzy sets with the fuzzy system. PDC controller can describe as follows:

IF \( z_1 \) is \( M_1 \) and and \( z_p \) is \( M_p \)
THEN \( u(t) = -G_i x(t) \)

For \( i=1,2, \ldots r \) Where \( G_i \) are the feedback gains.

Where \( u(t) = \frac{\sum_{l=0}^{l=\infty} w_i(t) G_i x(t)}{\sum_{l=0}^{l=\infty} w_i(t)} \)  
\( w_i(t) = \prod_{j=1}^{j=\infty} M_{ij} z_j(t) \)
The term \( M_{ij}(z_i(t)) \) is the grade of membership \( (z_i(t)) \) in \( M_{ij} \). Where the feedback gain can be calculated with the help of the state feedback law and the rules are as follows:

\[ G_i = z_{ma}(t) \times (A_i) \]
\[ i = 1,2, \ldots n \]

\( z_{ma} \) can be as follows
\[ z_{ma} = [0,0,0, \ldots ,0,1] \times \varphi_{ci}^T \]
\( \varphi_{ci}^T = [B_i A_i B_i \ldots A_i^{n-1} B_i] \)
\[ i = 1,2, \ldots n \]

The equilibrium of a fuzzy control system is said to be asymptotically stable in the large if there exist common positive definite symmetric matrix \( P \) such that the following conditions (a) or (b) is satisfied:

(a): \( G_i^T P + PG_i^T < 0 \), \( i=1,2, \ldots, l \), \( j=1,2, \ldots, l \)  
(b): \( G P + PG_i^T < 0 \), \( i=1,2, \ldots, l \)

A. PDC Controller for Magnetic Levitation System

For the designing the controller for maglev first of all we have to linearize the nonlinear model of the plant. The linearized model of the Magnetic Levitation System is as follows:

\[ \ddot{x} = \frac{2g}{x_i^2} x - \left( \frac{2}{x_i^2} \sqrt{\frac{K}{m}} \right) u \]

Now here we used Takagi-Sugeno fuzzy model which is based on the PDC (Parallel Distributed Compensation). Here we consider the equilibrium position of the ball is between 2 to 3 cm. The state space can be model with the help of sugeno rule as follows:

IF \( z_1 \) is \( M_1 \) and and \( z_p \) is \( M_p \)
THEN \( \ddot{x}(t) = A_i x(t) + B_i u(t) \)

With the help of linearization technique, we determine the state matrices \( A_i, B_i \) as follows:

\[ A_i = \begin{bmatrix} 0 & 1 \\ \frac{2K}{x_i^2} & 0 \end{bmatrix} \]
\[ B_i = \begin{bmatrix} 0 \\ -\frac{2}{x_i^2} \sqrt{\frac{K}{m}} \end{bmatrix} \]

According to the equilibrium position of the ball the rules of the TS fuzzy model are as follows:

IF \( z_1 \) is \( M_1 \) and \( z_2 \) is \( M_2 \)
THEN \( \ddot{x} = \frac{2g}{x_i^2} x - \frac{2}{2x_i^2} \sqrt{\frac{K}{m}} \) u \( 13 \)
IF \( z_1 \) is \( M_2 \) and \( z_2 \) is \( M_1 \)
THEN \( \ddot{x} = \frac{2g}{x_i^2} x - \frac{2}{2x_i^2} \sqrt{\frac{K}{m}} \) u \( 14 \)
IF \( z_1 \) is \( M_1 \) and \( z_2 \) is \( M_2 \)
THEN \( \ddot{x} = \frac{2g}{x_i^2} x - \frac{2}{2x_i^2} \sqrt{\frac{K}{m}} \) u \( 15 \)
IF \( z_1 \) is \( M_2 \) and \( z_2 \) is \( M_1 \)
THEN \( \ddot{x} = \frac{2g}{x_i^2} x - \frac{2}{2x_i^2} \sqrt{\frac{K}{m}} \) u \( 16 \)

Where \( g = 9.81 \text{m/s}^2 \), \( K = 2.3142*10^{-4} \) and \( m = 22*10^{-3} \) Considering the fact that the equilibrium points of the ball is lie between 2 to 3 cm. The membership function are as follows:

![Fig 1: Membership function](http://www.ijsret.org)
The feedback gains can be calculated with the help of state feedback laws as follows:
\[ G_1 = [0 \quad 3.1392], \quad G_2 = [0 \quad 2.5839], \quad G_3 = [0 \quad 2.04048], \quad G_4 = [0 \quad 1.61] \]

Considering the relation in (10) and (11) matrix \( P \) can be calculated as follows:
\[ P = \begin{bmatrix} 2.63 & 2.58 \\ 2.58 & 4.28 \end{bmatrix} \]

IV. SIMULATION AND RESULTS

By the use of these initial conditions, we simulate the nonlinear magnetic levitation system. The simulation results show that this system is stable in all initial conditions.

V. CONCLUSION

In the above paper, here is an intelligent controller has been designed for the Magnetic Levitation System which is based on the Takagi Sugeno type Fuzzy model and Parallel Distributed Compensation technique. In this technique we have change the non-linear plant of the Maglev into a series of linear subsystems. All linear subsystem will be controlled individually and distinct sub controllers will be comprised in a Fuzzy function basis. The Fuzzy function basis under the control of the linear controllers relates to the system a controlling signal applicable to the current system condition based on linear modeling of the system.

In this paper, the method which is used to design the controller for the nonlinear plant of the Magnetic Levitation System can make the system stable for all equilibrium point. Simulation results show that TS-PDC type fuzzy controller has shorter settling time than other controllers. PDC controller has easier preparation and mathematical control.

REFERENCES