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Neural Control of Magnetic Suspension Systems

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Abstract

Magnetic suspension and balance systems have been investigated and utilized in a variety of application areas for more than fifty years (see [5] for a comprehensive bibliography). These applications include magnetic suspension wind tunnels for aerodynamic testing, magnetically levitated bearings and rotors for high performance machines, magnetic suspension and melting of metal ingots for die casting, and magnetically levitated vehicles. With recent advances in superconductor technology and sensor design, new applications areas are beginning to emerge in space science, and vacuum and surface physics.

Since magnetic suspension systems are naturally unstable in open loop, a reliable stabilizing controller is an integral part of their design. In applications where plant uncertainty is low, measurement quality is high, and linear control techniques are directly applicable, the design process is well defined and usually successful. For example, in traditional wind tunnel applications where a model containing a magnetic core is suspended in an equilibrium state for aerodynamic testing, the designer has significant knowledge and control of the environment in which the suspension system is to operate. The mass and geometry of the model are precisely known, instrumentation of the system is usually very complete, and environmental disturbances, for example to the optical position sensors, can be controlled to a large degree. Furthermore, for small and large air-gap systems where the model is to be suspended in quasi-steady-state about one or more operating points, a linear controller can normally be manually tuned to yield a functional design.

Linear control techniques are usually inadequate for a large air-gap system which is to be operated dynamically over a large neighborhood of an equilibrium point. This is primarily due to the strong nonlinearities associated with the plant. Furthermore, the stabilization and control of a nonlinear plant in the presence of uncertainty is largely an open problem at present. In the last few years, an alternative approach to nonlinear compensation has begun to emerge based on research concerning artificial neural networks in the context of controls. (For a good overview of the area see [3].) The basic idea behind this approach is that an array of simple nonlinear devices referred to as neurons can be interconnected via a *generic* learning algorithm, for example back-propagation, so as to immulate a dynamic or static nonlinear input-output map. The learned map can be either the input-output behavior of the plant or that of a nonlinear compensator which has been taught to deliver a desired closed-loop response. The primary advantages to such an approach are:

- Precise knowledge of the plant is not a prerequisite for training a neural network;
- Desired closed-loop performance can be directly specified and attained with arbitrary precision (though at the expense of increasing controller complexity);

- Compensator complexity for most real-time applications is manageable with existing digital technology (programmable VLSI neural network chips are just beginning to become available);
- On-line learning can be used to adjust for time variations in the plant's input-output behavior.

The purpose of this research program is to design, build and test (in cooperation with NASA personnel from the NASA Langley Research Center) neural controllers for two different small air-gap magnetic suspension systems. The general objective of the program is to study neural network architectures for the purpose of control in an experimental setting and to demonstrate the feasibility of the concept. The specific objectives of the research program are:

- To demonstrate through simulation and experimentation the feasibility of using neural controllers to stabilize a nonlinear magnetic suspension system;
- To investigate through simulation and experimentation the performance of neural controllers designs under various types of parametric and nonparametric uncertainty;
- To investigate through simulation and experimentation various types of neural architectures for real-time control with respect to performance and complexity;
- To benchmark in an experimental setting the performance of neural controllers against other types of existing linear and nonlinear compensator designs.

To date, the first one-dimensional, small air-gap magnetic suspension system has been built, tested and delivered to the NASA Langley Research Center. The device is currently being stabilized with a digital linear phase-lead controller. The neural controller hardware is under construction. Two different neural network paradigms are under consideration, one based on hidden layer feedforward networks trained via back propagation and one based on using Gaussian radial basis functions trained by analytical methods related to stability conditions. Some advanced nonlinear control algorithms using feedback linearization [1,2] and sliding mode control [4] are in simulation studies.

References

[1] B. Fernández, "Robust Feedback Linearization Through Sliding Mode Control," in *Proc. 29th IEEE CDC*, Honolulu, HI, pp. 3398-3399, 1990.

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