# Fuzzy Logic Control of a Magnetic Suspension System Using xPC Target

by

Stephen Friederichs

Project Advisors:

Dr. Winfred Anakwa and

Dr. In Soo Ahn

Submitted:

December 1, 2004

EE451 Senior Capstone Project

# Summary

The goal of this project is to create a fuzzy logic controller to stabilize and control a magnetic suspension system using Simulink and an xPC Target box. The fuzzy logic controller will be built and tested in Simulink, and then compiled into C code to be used on the xPC Target box. The xPC is outfitted with A/D and D/A converters to digitize the error voltage and produce the correction voltage necessary to control the system. The controller will be optimized to produce zero steady state error, and minimize rise time and overshoot.

# Functional Description

Figure 1 shows the high-level block diagram for the entire system. A more detailed description of each sub-system follows.

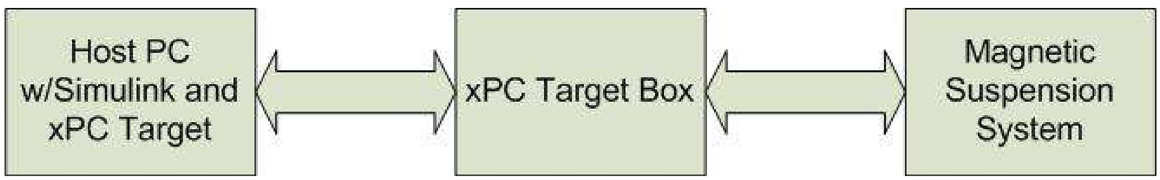



Fig. 1 – High Level Block Diagram

## Host PC w/Simulink and xPC Target

The PC contains the Simulink and xPC Target application. All of the control models are created using Simulink on the PC. Once complete, the models are compiled into C code, and then transferred to the xPC Target Box using an ethernet connection.

## xPC Target Box

The xPC target box acts as the real-time controller for the magnetic suspension system. The models from the PC are stored on the xPC target box as C code. Program execution and data retrieval are controlled by the host PC via ethernet. The xPC target box contains analog to digital and digital to analog converters which allow it to take data from the magnetic suspension system, and apply control signals to it.

## Magnetic Suspension System

The magnetic suspension system suspends a metal ball in a magnetic field. Its inputs include a set point, and a reference input. The set point describes the origin of the coordinate plane for the suspension system, which is where the ball will hang at equilibrium. The reference input allows a waveform to be entered for the ball to follow. The outputs of the system include an error signal, and a ball position signal. These are both sent to the xPC Target Box through the A/D converter to control the system.

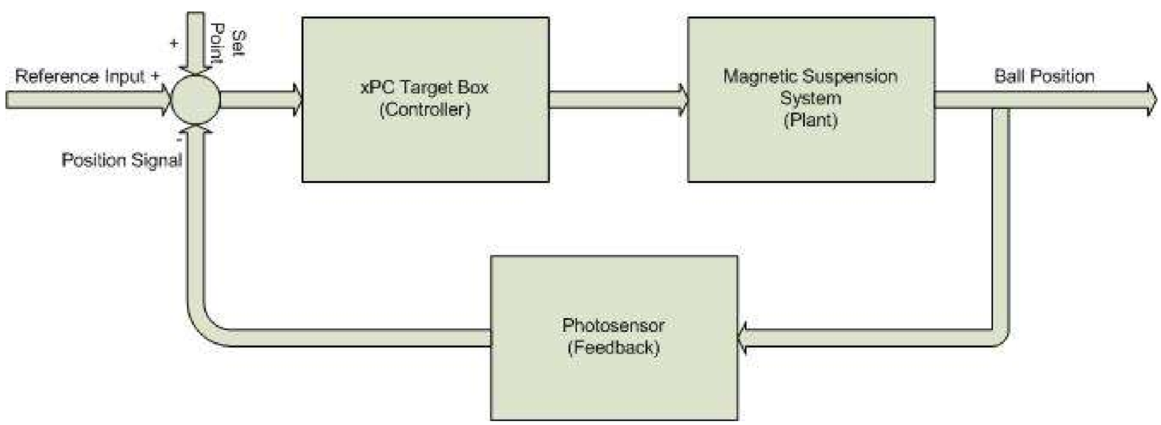



Fig. 2 – Control Block Diagram

Figure 2 shows the detailed control block diagram for the system. The reference input, set point, and ball position signals combine to form the error signal. The error signal is entered into the xPC Target box, which acts as the controller. The correction signal from the controller is applied to the magnetic suspension system, which acts as the plant. The photosensor measures the ball position and feeds that information to the controller. A detailed diagram of the magnetic suspension plant is shown in figure 3.

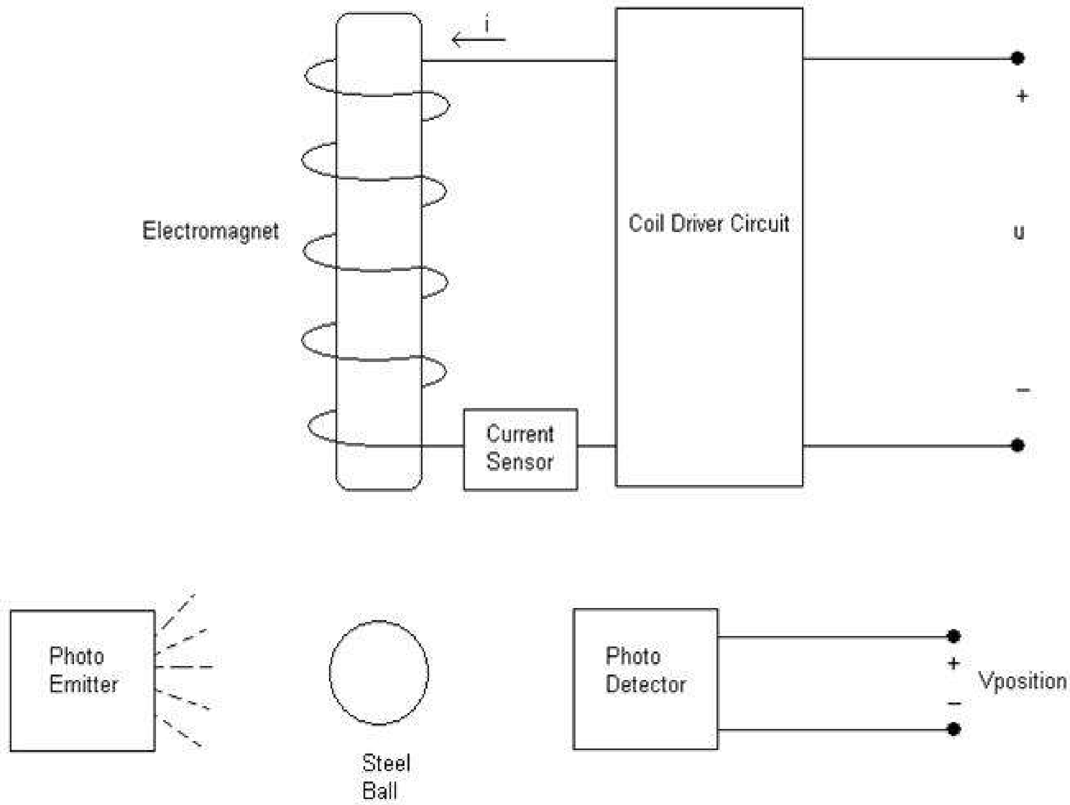



Fig. 3 – Plant Diagram

The ball is suspended using the electromagnet. The coil is driven using the coil driver circuit, the input of which is the voltage *u*. This voltage is applied directly by the xPC through the digital to analog converter. The current sensor is a one ohm resistor in series which allows measurements of current to be taken. The ball position is determined by the ball breaking a beam of light which is detected with the photo detector. This information is fed back to the xPC through the analog to digital converter.

# System Block Diagram

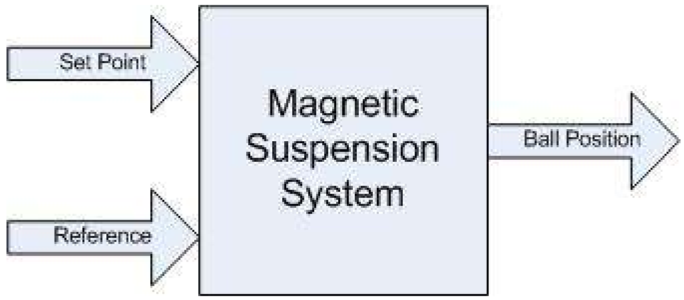



Fig. 4 – Overall System Block Diagram

Figure 4 shows the overall system block diagram. The set point voltage determines where the ball should hang at steady state. This along with a reference input waveform is entered into the overall system, which changes the position of the ball to match the reference input.

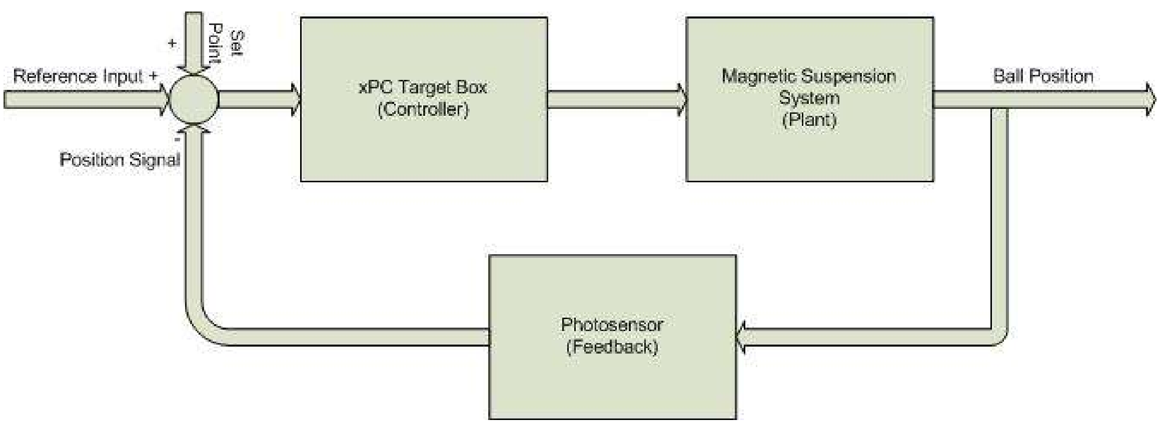
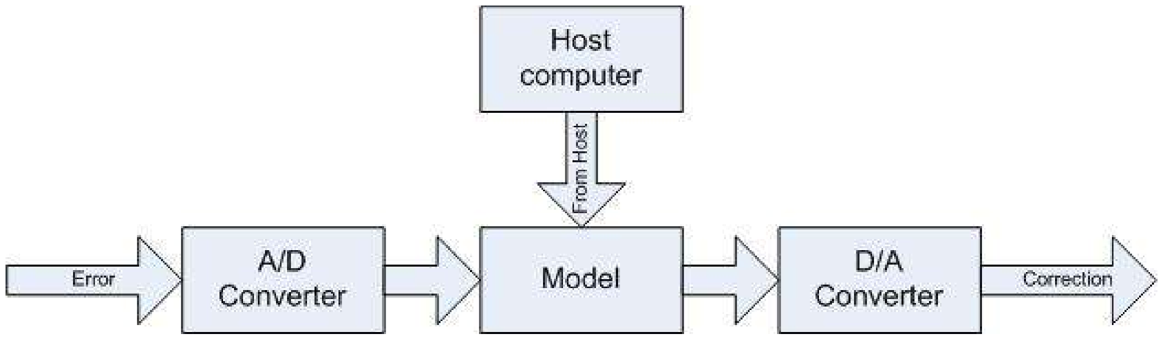



Fig. 5 – System Internal Block Diagram

Figure 5 shows the internals of the system. The set point, reference waveform, and negative of the ball position are summed to provide an error signal. This signal is fed into




the controller, which produces a correction signal for the plant. The ball position changes according to the correction signal, and is fed back to the input via the photosensor.

Fig. 6 – Controller Block Diagram

Figure 6 shows the block diagram for the controller. The error signal from the summer is sent through the A/D converter to produce a digital signal for the digital controller in the xPC . The mathematical model of the controller is downloaded from a host PC to the xPC target. The model determines the correction based on the error signal, and the resulting digital signal is turned into an analog signal via the D/A converter. The sampling time of the controller is 1ms. The A/D and D/A converter have ranges of +-10V.

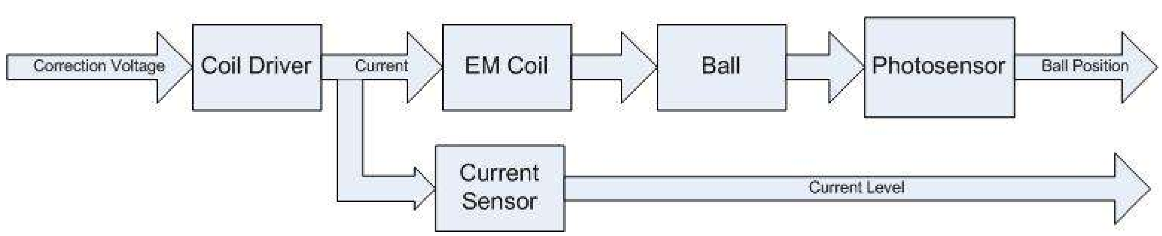



Fig. 7 – Plant Block Diagram

Figure 7 shows the plant block diagram. The correction voltage from the controller is applied to a coil driver which changes the voltage to a current. This current is sampled by a 1 ohm resistor used as a current sensor. The current runs through an electromagnetic coil, which suspends the steel ball in its field. The ball position is measured by a photosensor.

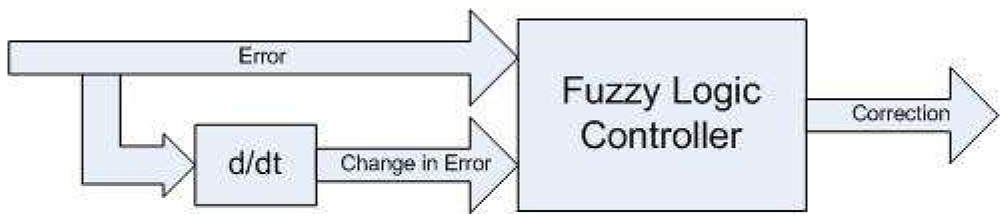



Fig. 8 – Controller Model Block Diagram

The fuzzy logic controller operates as a model on the xPC target box. The system is shown in figure 8. The error signal from the A/D converter is fed into the controller, and the change in error is computed and fed in as well.

The fuzzy logic controller operates as seen in the flowchart in figure 9. The inputs are 'fuzzified' according to the input membership functions defined in the system. The input membership functions are cut off at the maximum level of certainty as expressed by the fuzzified inputs. Then, the certainty of application of each rule is determined using the product method on the applicable inputs. The final value of each output membership function is chosen as the maximum certainty of application among the applicable rules.

The final output value is found by finding the value which represents the center of gravity of the new output membership functions..

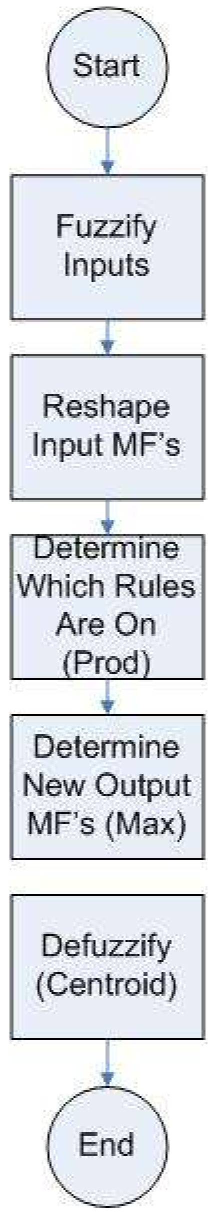
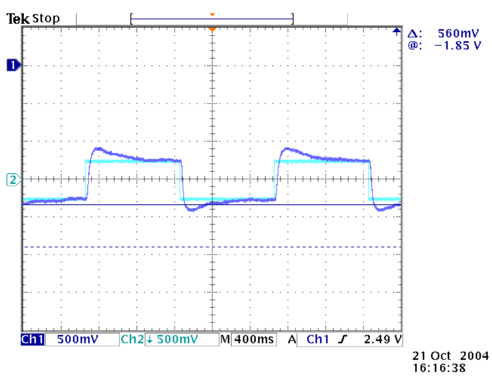



Fig. 9 – Fuzzy Logic Flow Chart

# Preliminary Results

The work up to this point has concerned creating a fuzzy logic controller to stabilize the magnetic suspension system. First, the previous work was recreated in Simulink to ensure that the system would behave appropriately. This model was compiled and sent to the xPC, where it produced the results seen in figure 10.



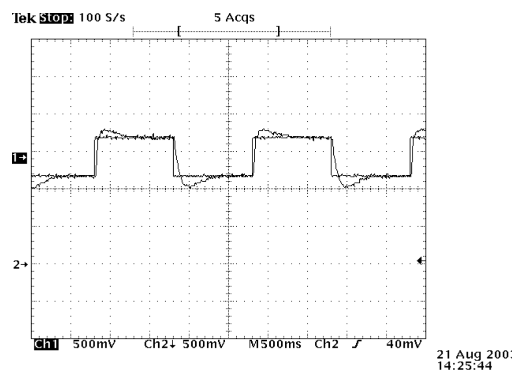




Fig.10 – Results using the previous controller

Fig.11 –Results from the previous work

These results agreed with the results seen in the previous work, seen in figure 2. At this point, a simple fuzzy logic system was designed and implemented on paper, and then recreated in Matlab to gain familiarity with the tools and ensure the functioning of a fuzzy logic system in Matlab as compared to theoretical calculations.

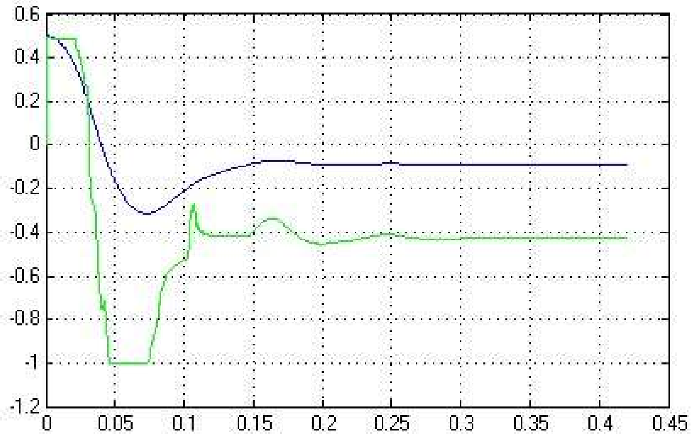



Fig. 12-Simulink Simulation of stabilized magnetic suspension system

(Ball position on top)

After this system was verified, a fuzzy logic controller was created to attempt to stabilize the magnetic suspension system. This first generation controller made decisions based on the error in the system. This controller failed to stabilize the system. A second generation employed change in error as well as error, and had 15 membership functions and 56 rules. It stabilized the system as seen in figure 12, but was too complex to be run on the xPC. A third generation model employs error and change in error, and also uses gain adjustment on all input and output blocks, so the controller can be tuned without changing rules or membership functions. This system employs 8 membership functions, and 16 rules. It runs on the xPC with a step time of 1ms. It is currently being tuned to stabilize the system and produce zero steady state error.

# Schedule

## Project Tasks

- Create fuzzy logic controller using Simulink model to stabilize magnetic suspension system
- Verify behavior of Simulink model
- Tune model parameters to minimize steady state error, rise time, and percent overshoot
- Use advanced techniques (such as genetic algorithms or neural networks) to generate a fuzzy logic controller and compare it to the hand-made controller.

### Schedule

<table>
<tr><th></th><th colspan="2">Hand-Made Controller</th><th>Advanced Controller</th></tr>
<tr><td>12/2/2004</td><td colspan="3">Present Project</td></tr>
<tr><td>12/9/2004</td><td colspan="3">Finals/Study Day</td></tr>
<tr><td rowspan="2">12/16/2004</td><td colspan="3">Christmas Break</td></tr>
<tr><td>Research speed improvements</td><td>Research stabilization methods</td><td>Research advanced controller methods</td></tr>
<tr><td>1/22/2005</td><td>Begin xPC implementation</td><td rowspan="6">Tune controller in Simulink</td><td></td></tr>
<tr><td>1/29/2005</td><td>Address xPC implementation issues</td><td></td></tr>
<tr><td>2/6/2005</td><td rowspan="4">Continue implemenation on xPC</td><td rowspan="4">Implement advanced controller</td></tr>
<tr><td>2/13/2005</td></tr>
<tr><td>2/20/2005</td></tr>
<tr><td>2/27/2005</td></tr>
<tr><td>3/5/2005</td><td colspan="2" rowspan="6">Document hand-made controller</td><td></td></tr>
<tr><td>3/12/2005</td><td></td></tr>
<tr><td>3/19/2005</td><td></td></tr>
<tr><td>3/26/2005</td><td rowspan="3">Finalize advanced controller</td></tr>
<tr><td>4/2/2005</td></tr>
<tr><td>4/9/2005</td></tr>
<tr><td>4/16/2005</td><td colspan="3" rowspan="3">Documentation, presentation</td></tr>
<tr><td>4/23/2005</td></tr>
<tr><td>4/30/2005</td></tr>
</table>

# Equipment List

Magnetic Suspension System
xPC Target Box
Host PC
Oscilloscope (Tektronix TDS-3012)
Function Generator (HP E3630A)

# Bibliography


“Jose A. Lopez and Winfred K.N. Anakwa, "Identification and Control of a Magnetic Suspension System using Simulink and dSPACE Tools", Proceedings of the ASEE Illinois/Indiana Section 2004 Conference, March 26-27, 2004, East Peoria, Illinois, U.S.A., pp. 24-30.

Passino, Kevin and Yurkovich, Stephen. “Fuzzy control”, Addison-Wesley Longman, Inc, 1998.

Feedback Inc., 437 Dimmocks Mill Road, Hillsborough, North Carolina 27278. http://www.fbk.com/

Simulink, Version 5.1, The MathWorks Inc., Natick, MA 01760, 2003.

xPC Target Box, The MathWorks Inc., Natick, MA 01760, 2003.

xPC Target Software, The MathWorks Inc., Natick, MA 01760, 2003.