Bergmans Mechatronics LLC

Real-Time, Closed-Loop Control of an Unstable System using CompactRIO and LabVIEW RT

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National Instruments LabVIEW User Group Meeting

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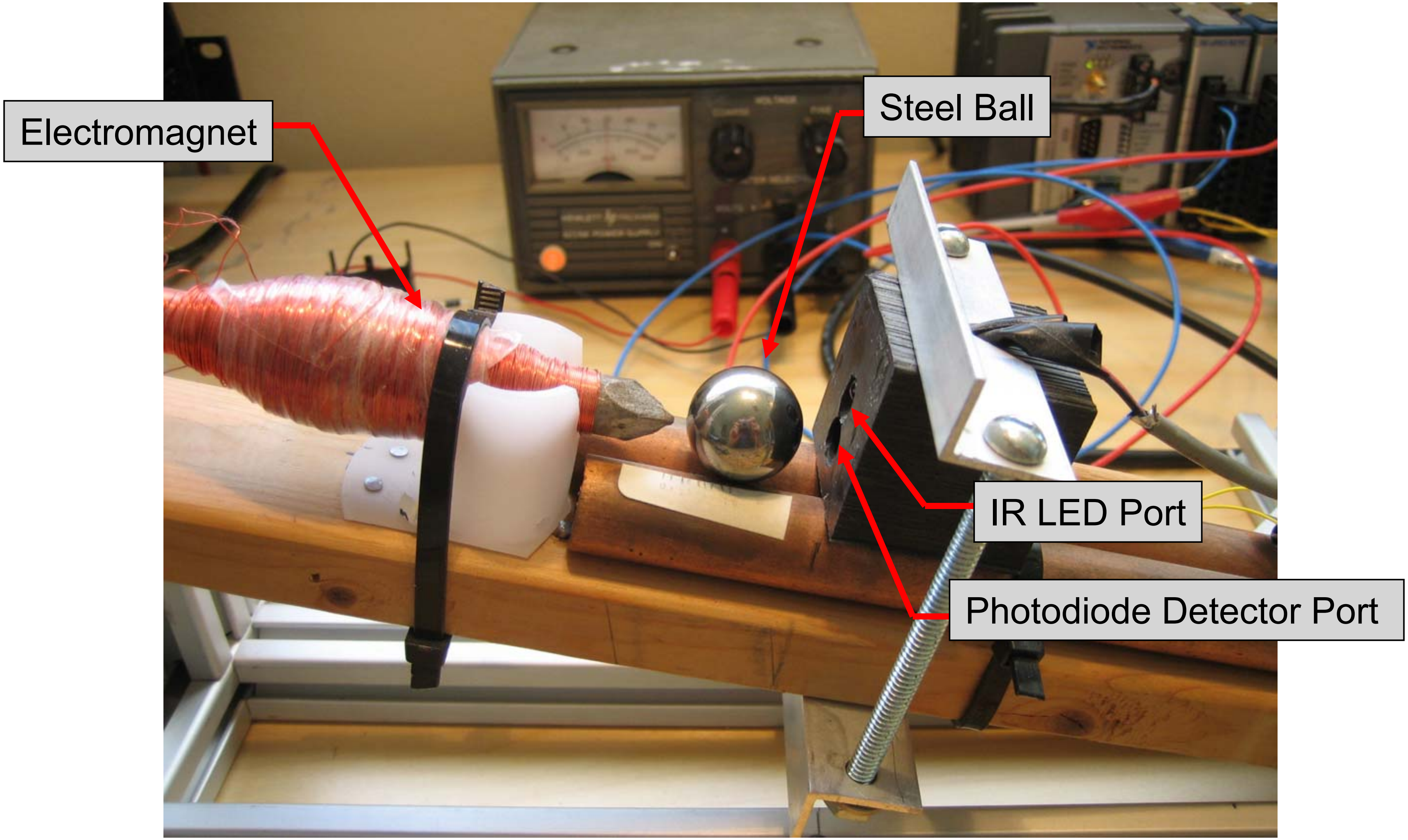
System Components



Presentation Objectives

- Demonstrate use of CompactRIO hardware and LabVIEW RT software for implementation of a control loop operating at a high processing rate
- Demonstrate use of closed-loop control system to control an unstable device
- High-level overview of controller design using root-locus design method

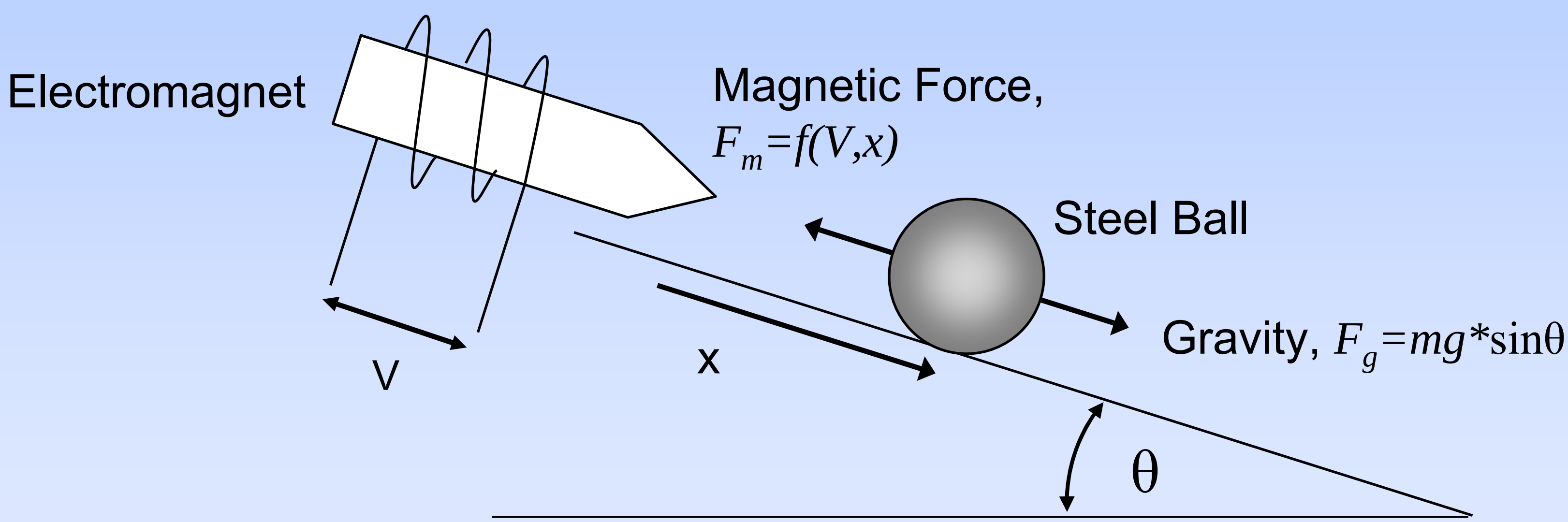
Motivations for Control Demo

- General interest in control technology
- Interest in more determinism and higher processing rates for BML projects

Ball on Ramp Controller

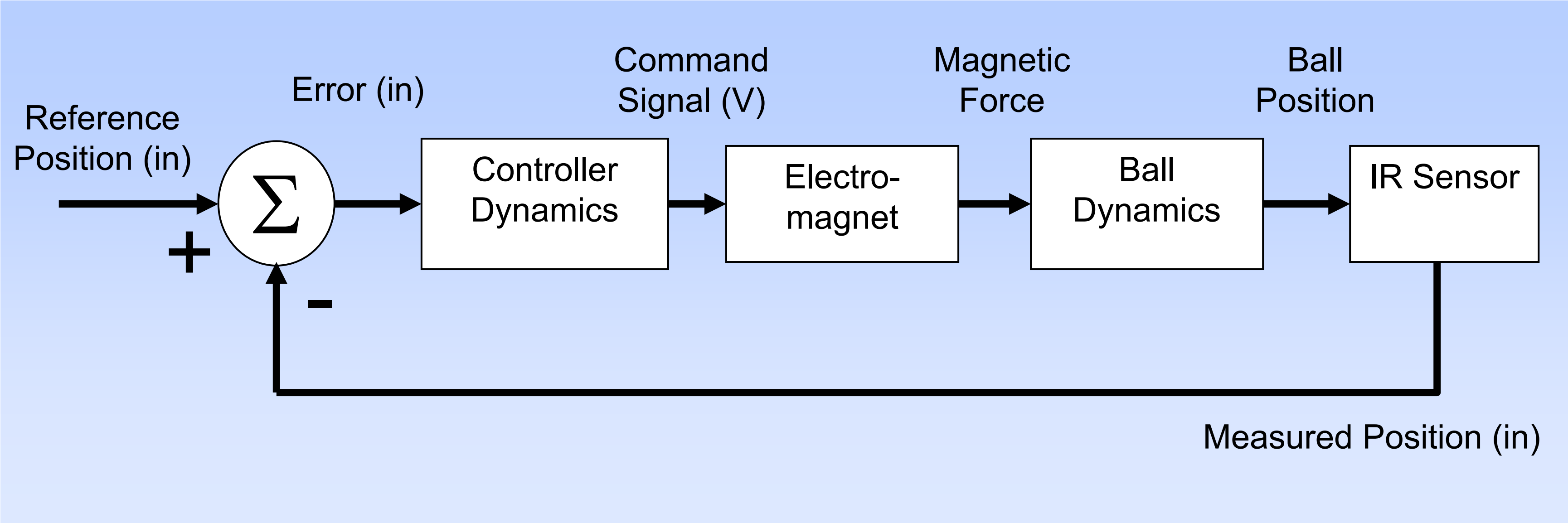
- Demonstration of Closed-Loop Control of an Unstable "Plant"
- Ball on Ramp is unstable without control
  - ball too close to magnet – ball rolls up
  - ball too far from magnet – ball rolls down

Basic "Plant" Components

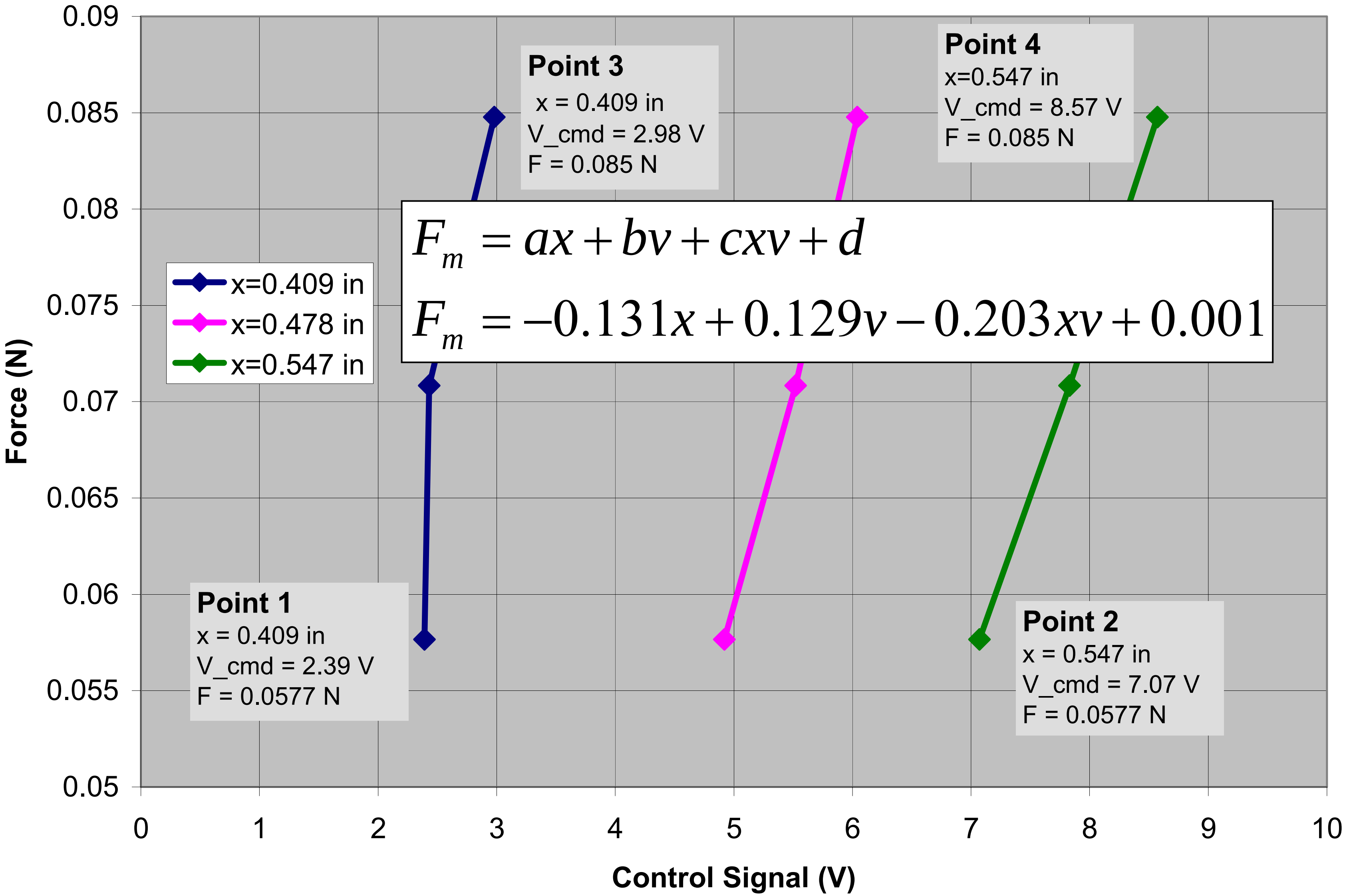


Control System Block Diagram

- Closed-loop controller continuously adjusts magnet current to minimize error (ie maintain ball at reference position)
- Controller dynamics must respond appropriately to response of other system components



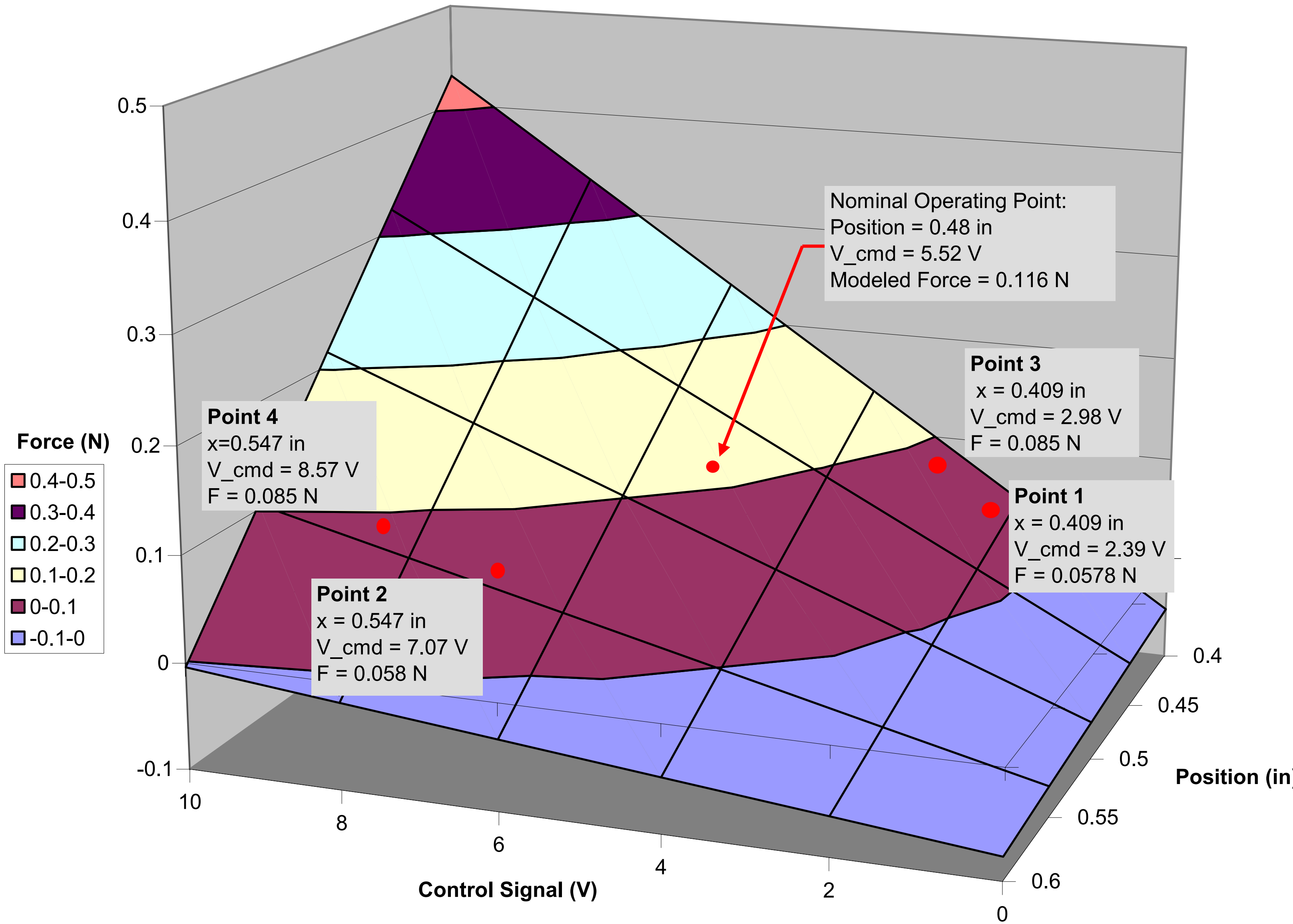
Electromagnet Characterization



$$F_m = ax + bv + cxv + d$$

$$F_m = -0.131x + 0.129v - 0.203xv + 0.001$$

Electromagnet Characterization



Linear Dynamic Model

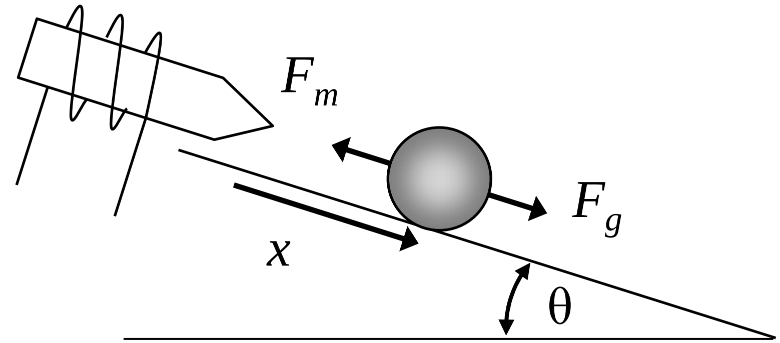
Magnetic Force (Linearized for operation at θ=14.8° → x_0=0.478 in, V_0=5.52 V)

$$F_m = ax + bv + cxv + d$$
$$\approx (a + cv_0)x + (b + cx_0)v + d$$
$$F_m = -1.254x + 0.032v + 0.537$$

Gravitational Force

$$F_g = mg\sin\theta$$
$$= (0.0283\,\mathrm{kg})\left(9.81\frac{\mathrm{m}}{\mathrm{s}}\right)*\sin 14.8^\circ$$
$$F_g = 0.071\,\mathrm{N}$$

Linear Dynamic Model



Equation of Motion

$$F_g - F_m = \frac{7}{5} m\ddot{x}$$

$$0.071 - \left(-1.254x + 0.032v + 0.537\right) = 0.001\ddot{x}$$

$$\ddot{x} - 1254x + 32v + 466 = 0$$

Linear Dynamic Modeling

Laplace Transform of Equation of Motion

$$\ddot{x} - 1254x + 32v + 466 = 0$$

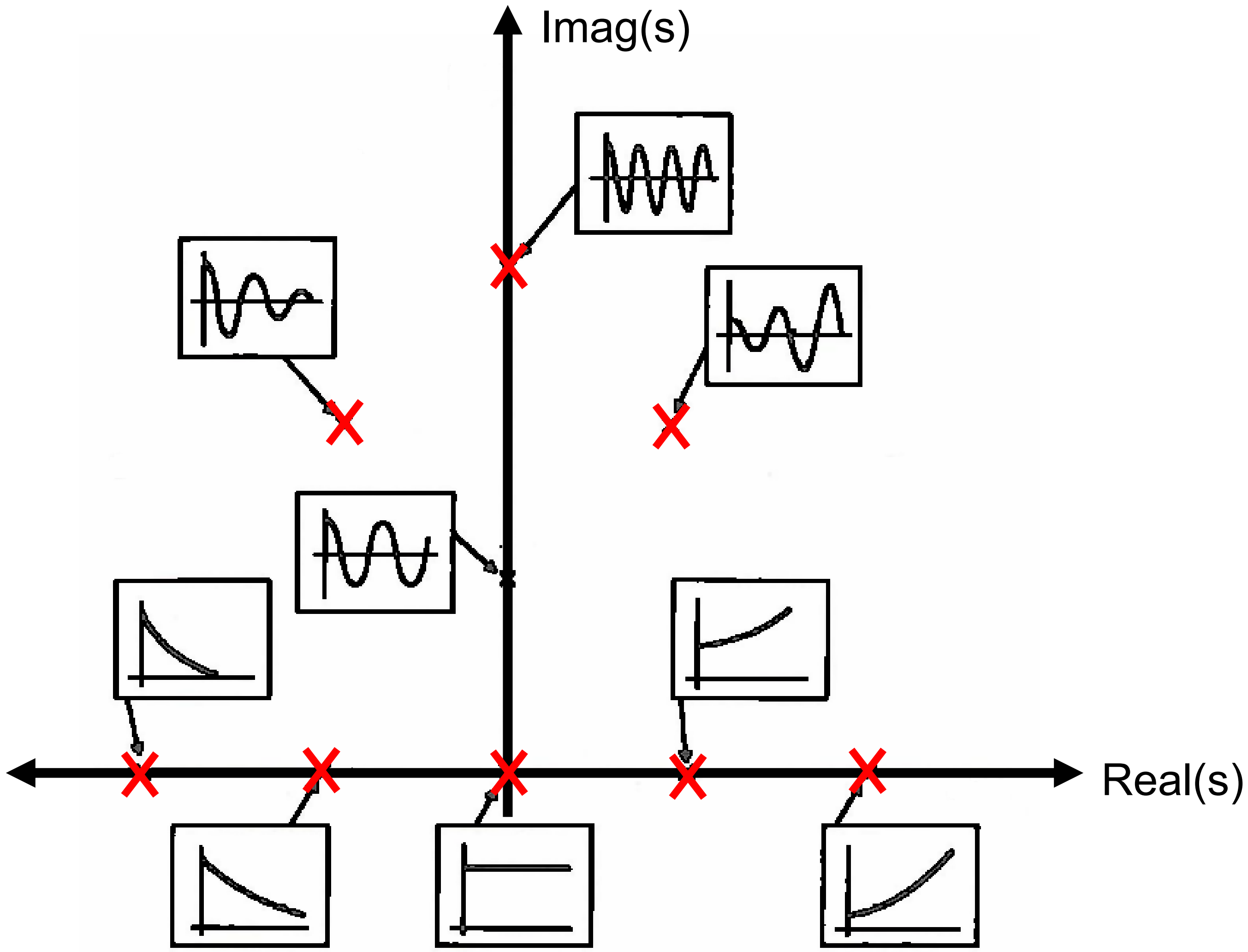
$$s^2 X(s) - 1254 X(s) + 32V(s) + 466 = 0$$

Transfer Function

$$X(s) = \frac{-32}{s^2 - 1254} V(s) + C$$

$$X(s) = \frac{-32}{(s + 35.4)(s - 35.4)} V(s) + C$$

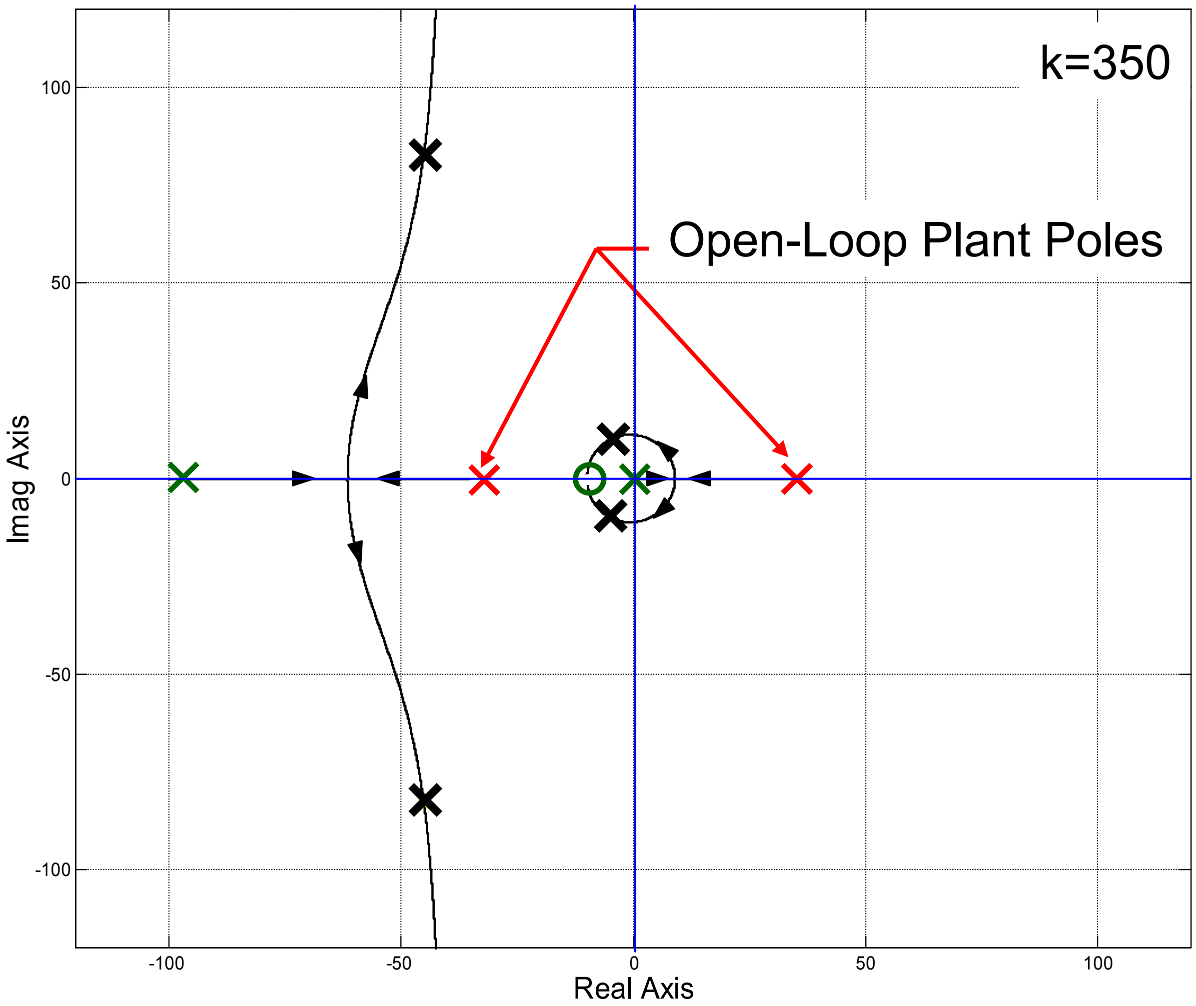
Impulse Response vs Pole Location



Ref: Figure 2.33 of Franklin, G.F., Powell, J.D., Emami-Naeini, A., “Feedback Control of Dynamic Systems”, Addison-Wesley, 1986.

Root Locus Design

Method enables systematic, graphical approach to developing controllers for complicated plants



Controller Dynamics

Transfer Function

$$V(s) = k\frac{(s+10)(s+10)}{s(s+100)}E(s)$$

K~=200 to 700

Discretized Controller Algorithm

Integrator Stage

$$y_n = y_{n-1} + x_n T$$

"Pole/Zero" Stage

$$y_n = \frac{y_{n-1} + x_n(1+aT)}{(1+bT)}$$

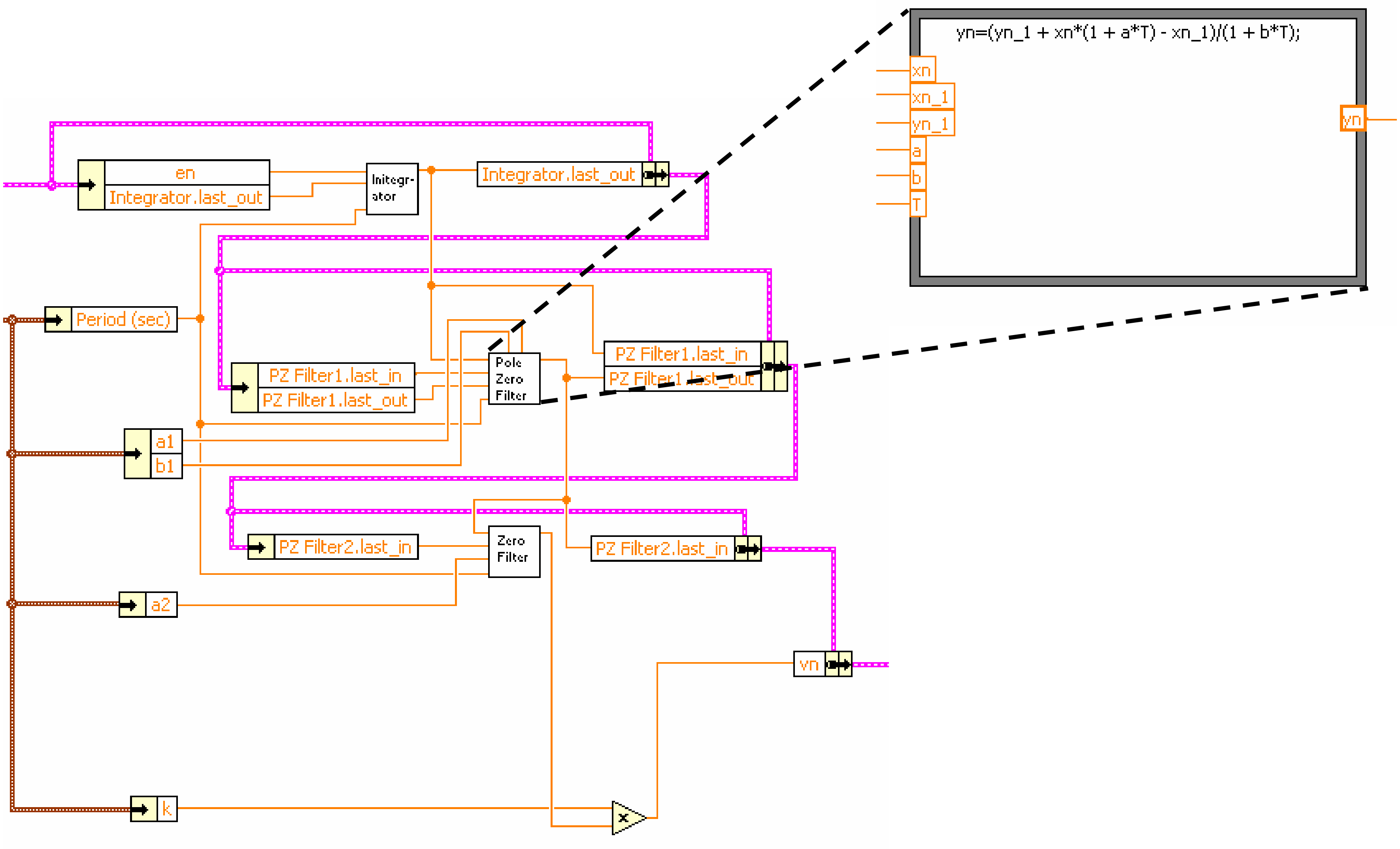
"Zero" Stage

$$y_n = \left(a + \frac{1}{T}\right)x_n - \frac{1}{T}x_{n-1}$$

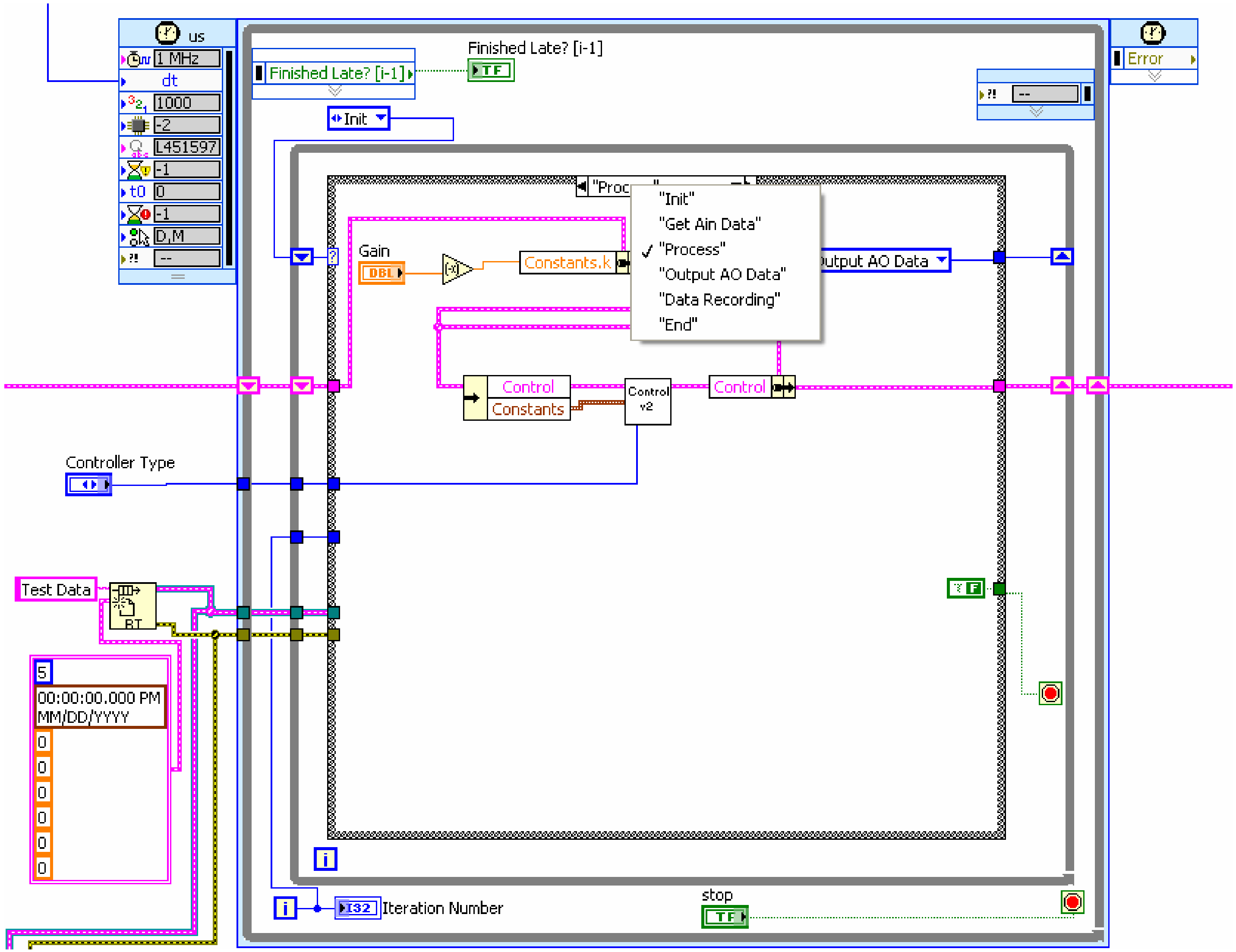
Gain Stage

$$y_n = kx_n$$

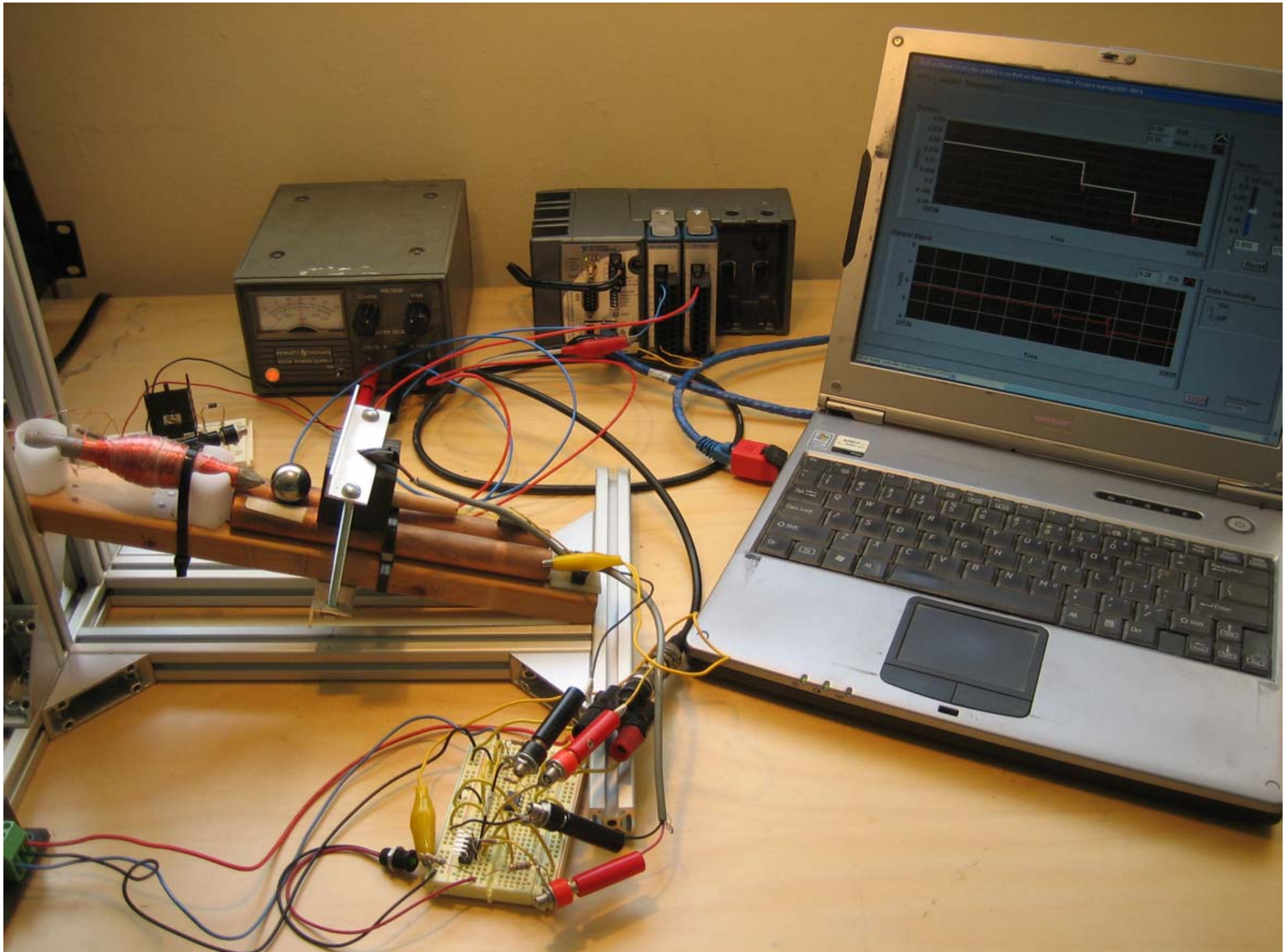
Controller Implementation in LabVIEW Real-Time



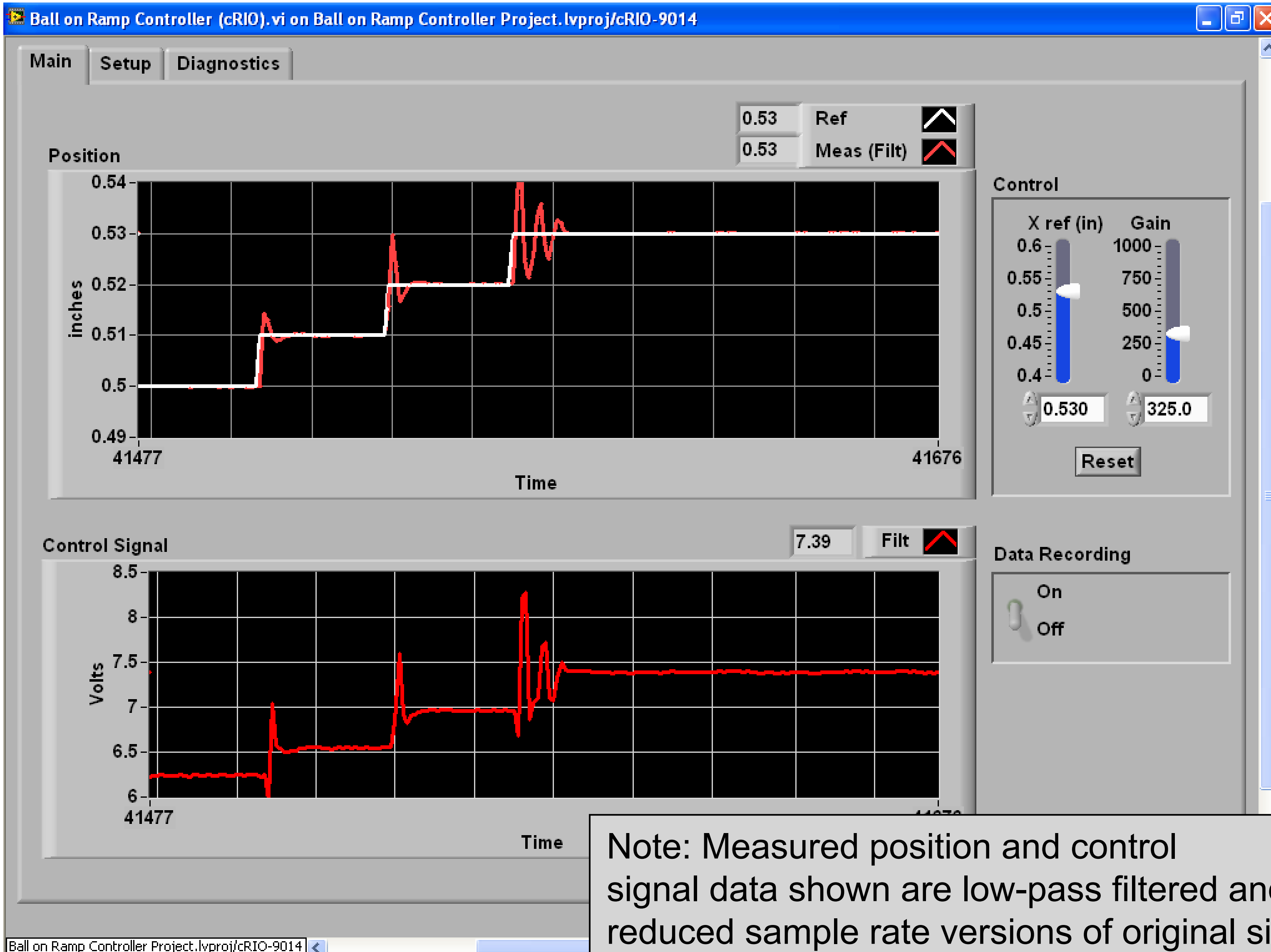
Controller Implementation in LabVIEW Real-Time



System Components

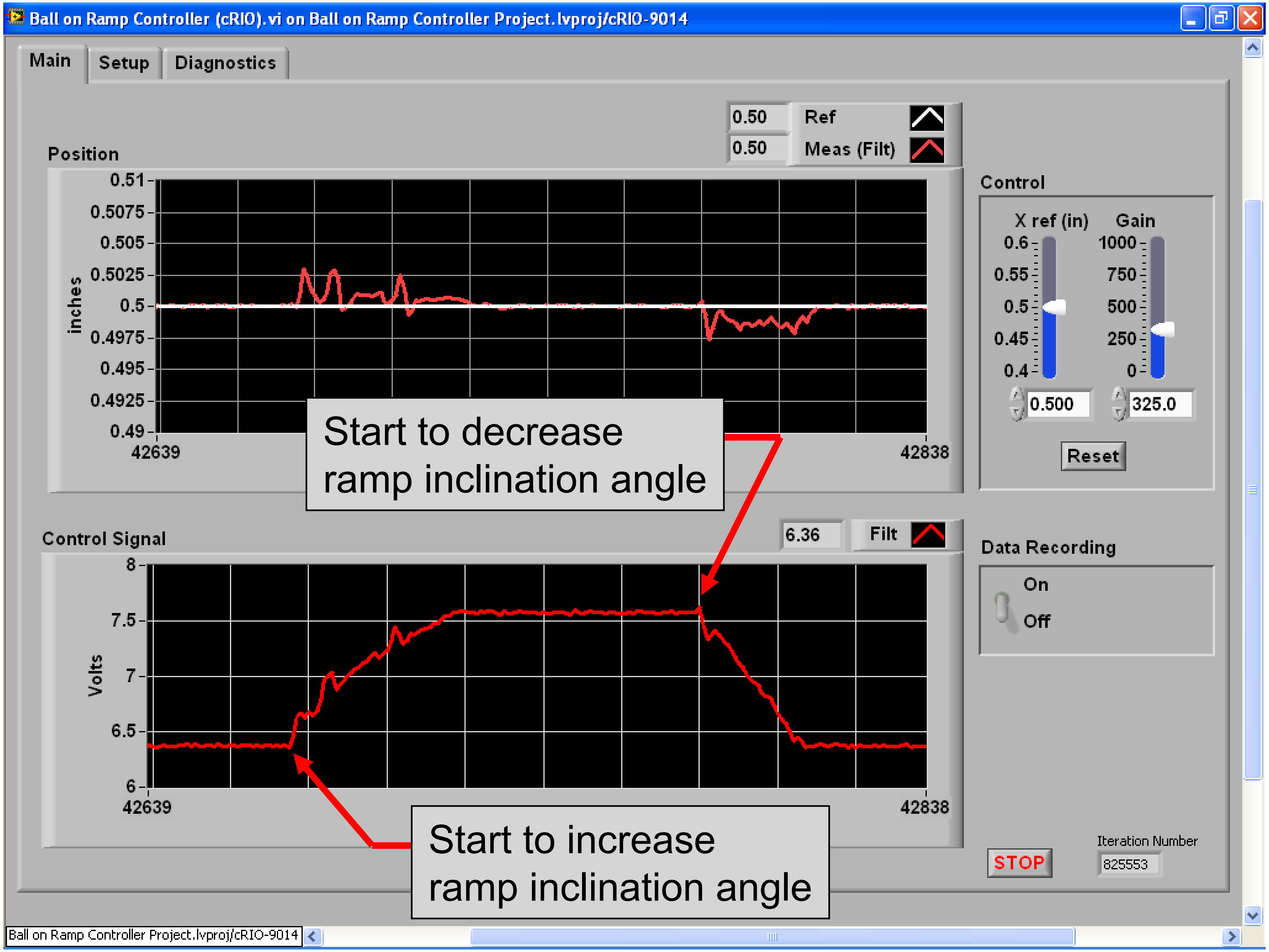


Step Response



Note: Measured position and control signal data shown are low-pass filtered and reduced sample rate versions of original signals

Disturbance Rejection (Transition between θ=14.8° and 21.2°)



System Performance

- 1000 Hz processing rate in LabVIEW RT on CompactRIO PowerPC Processor (3000 Hz should be feasible according to NI)
- 1000 Hz display update rate via ethernet on 2.8 GHz Celeron rackmount PC with 1 GB RAM
- 10 Hz display update rate via ethernet on 1.4 GHz AMD Athlon laptop with 224 MB RAM

Summary

- LabVIEW RT and CompactRIO
  - High processing rate
  - High determinism
  - Easy to program
  - Physically robust
- Closed-loop control of unstable systems is feasible
- Consider root-locus method for controller design

System Hardware Details

National Instruments Compact RIO System

- cRIO-9014 Controller
  - 400 MHz Freescale MPC5200 processor
  - 128 MB DRAM
  - Wind River VxWorks Operating System

- cRIO-9103 chassis
  - 4 module slots
  - Xilinx Virtex II FPGA

- cRIO-9215 analog input module
  - 4 differential input channels
  - 16 bit, +/- 10 V, 100 kS/s, simultaneously sampled

- cRIO-9263 analog output module
  - 4 analog output channels
  - 16 bit, +/- 10 V, 100 kS/s, updated simultaneously

System Hardware Pricing (from ni.com 10/28/09)

Item	Amount
cRIO-9014 Controller	2699
cRIO-9103 chassis	2499
cRIO-9215 analog input module	499
cRIO-9263 analog output module	379
Total	**$6076**

Single Board RIO

NI Embedded Software Evaluation Kit

LabVIEW Real-Time and LabVIEW FPGA Programming

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- Step-by-step tutorials for building FPGA-based and FPGA/microprocessor-based applications
- Fully documented, ready-to-run examples of common embedded tasks
- Extended evaluation version of LabVIEW software and LabVIEW Real-Time and LabVIEW FPGA modules
- Features daughterboard for easy interfacing that includes encoder, LEDs, and other interfaces
- Includes an NI Single-Board RIO device with at least 2 AO, 6 AI, and 8 TTL DIO lines

Overview **Pricing** Resources

Part Number	Description	Est Ship	US Dollars	Qty
780448-03	LabVIEW Embedded Platform Evaluation Kit 90 Days	12 - 20	$ 999.00	0
780449-03	LabVIEW Embedded Platform Evaluation Kit 180 Days	12 - 20	$ 1,199.00	0