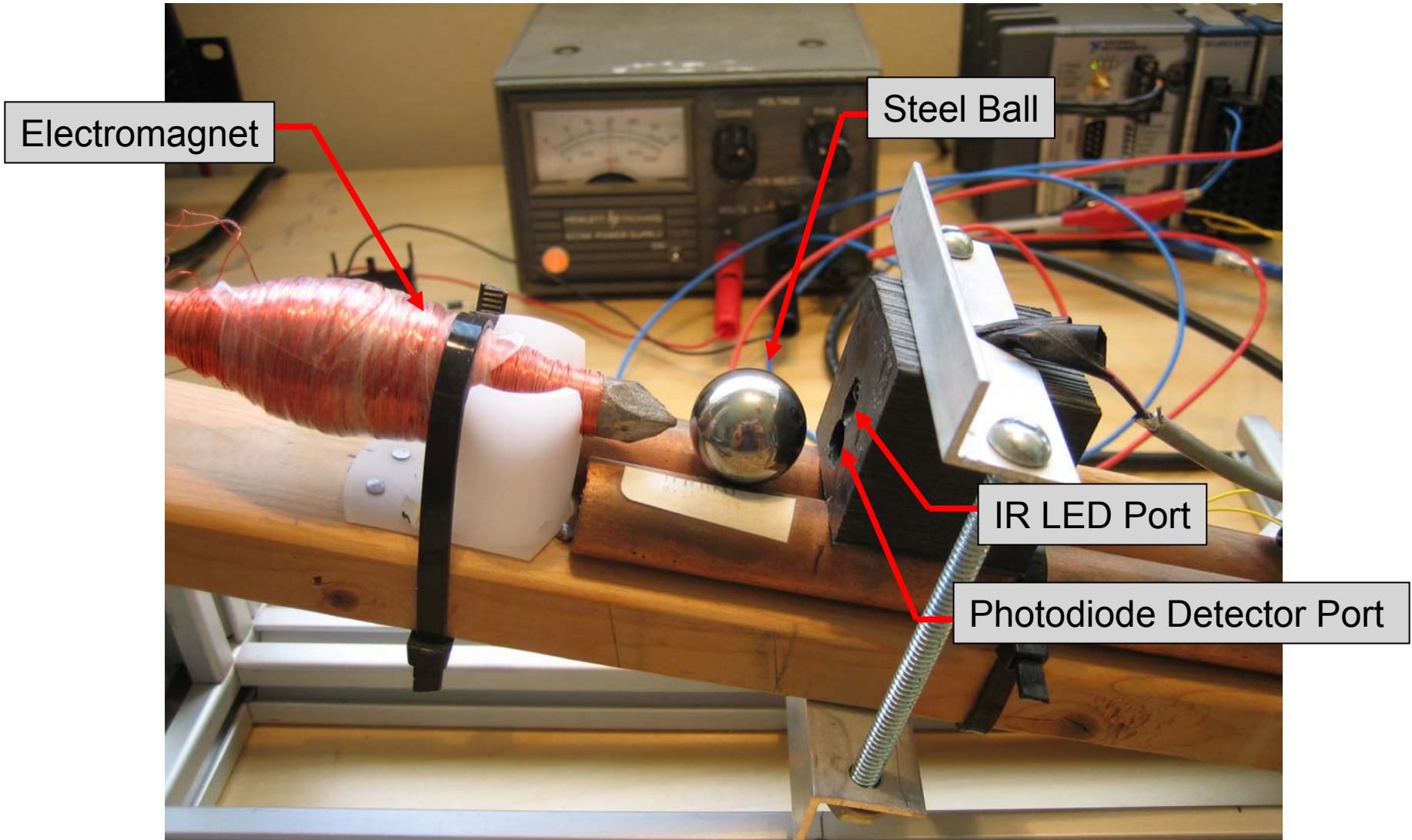

Bergmans Mechatronics LLC

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

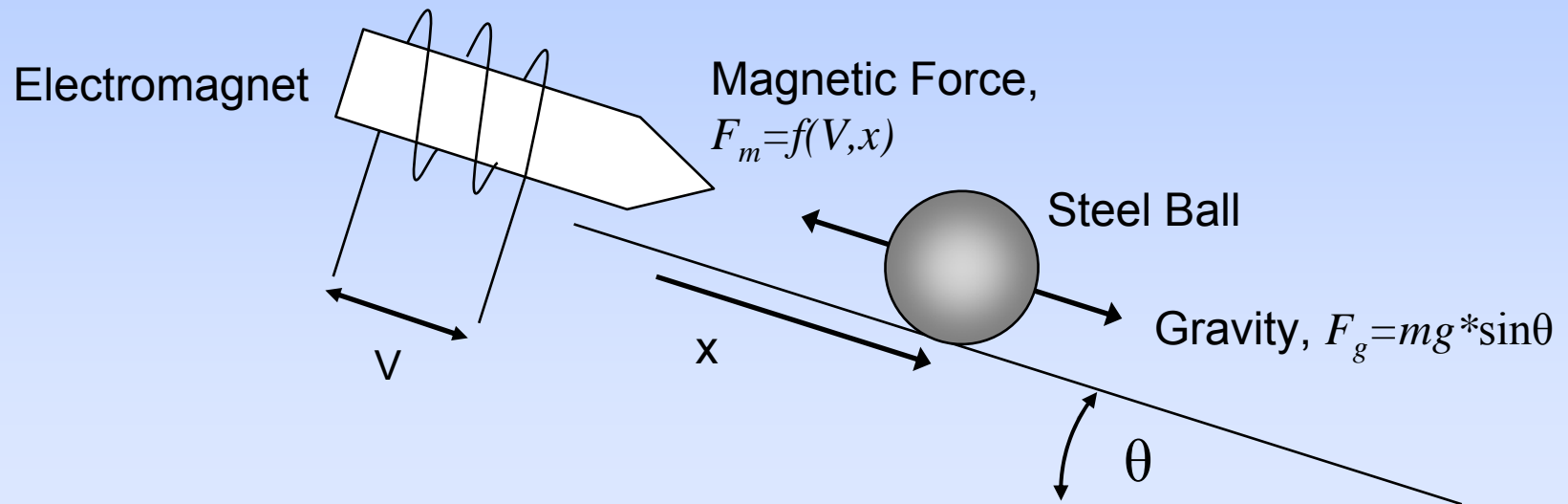
Motivations for Control Demo

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

Ball on Ramp Controller

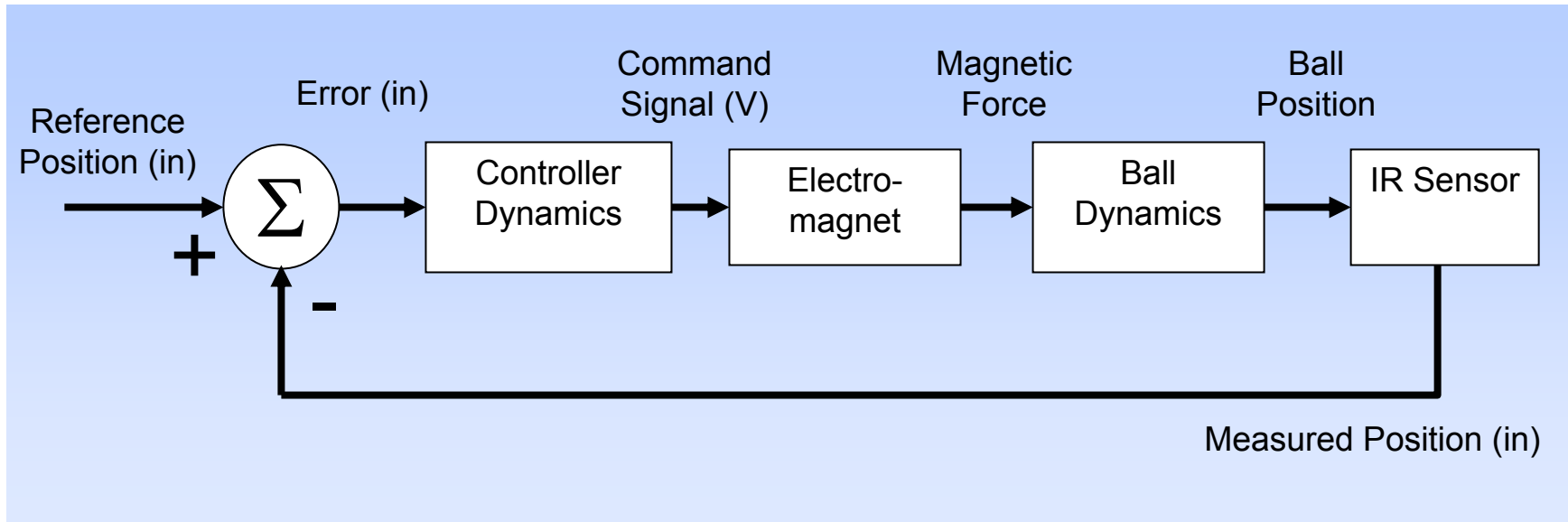
- Demonstration of Closed-Loop Control of an Unstable “Plant”
- Ball on Ramp is unstable without control
 - ball too close to magnet – ball rolls up
 - ball too far from magnet – ball rolls down

Basic “Plant” Components

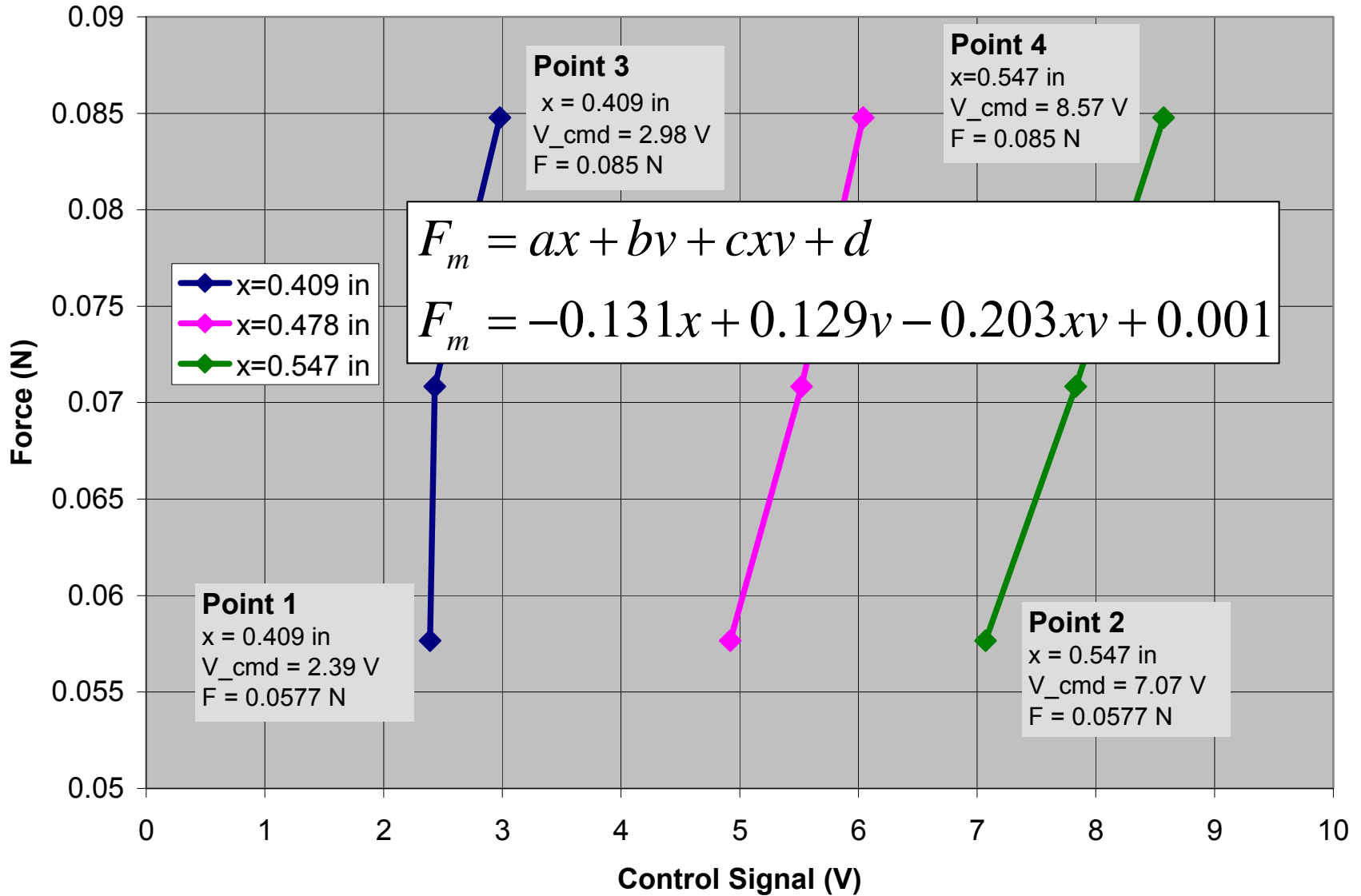


Control System Block Diagram

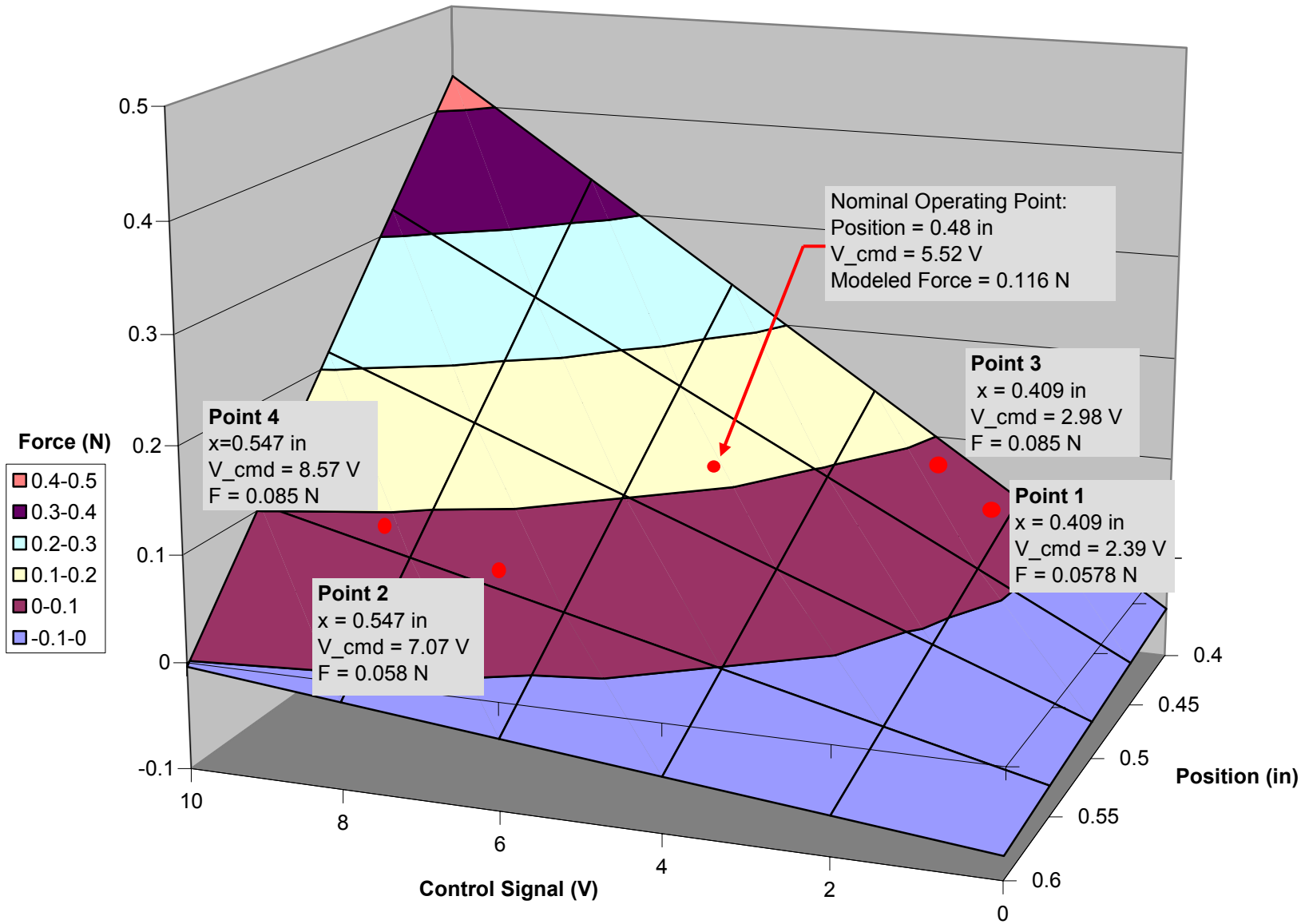
- Closed-loop controller continuously adjusts magnet current to minimize error (ie maintain ball at reference position)
- Controller dynamics must respond appropriately to response of other system components



Electromagnet Characterization



Electromagnet Characterization



Linear Dynamic Model

Magnetic Force (Linearized for operation at $\theta=14.8^\circ \rightarrow x_0=0.478$ in, $V_0=5.52$ V)

$$\begin{aligned}F_m &= ax + bv + cxv + d \\ &\approx (a + cv_0)x + (b + cx_0)v + d \\ F_m &= -1.254x + 0.032v + 0.537\end{aligned}$$

Gravitational Force

$$\begin{aligned}F_g &= mg \sin \theta \\ &= (0.0283 \text{ kg}) \left(9.81 \frac{\text{m}}{\text{s}} \right) * \sin 14.8^\circ \\ F_g &= 0.071 \text{ N}\end{aligned}$$

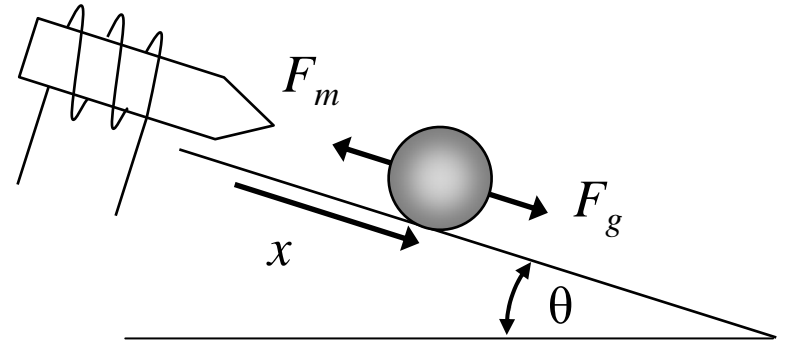
Linear Dynamic Model

Equation of Motion

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

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

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



Linear Dynamic Modeling

Laplace Transform of Equation of Motion

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

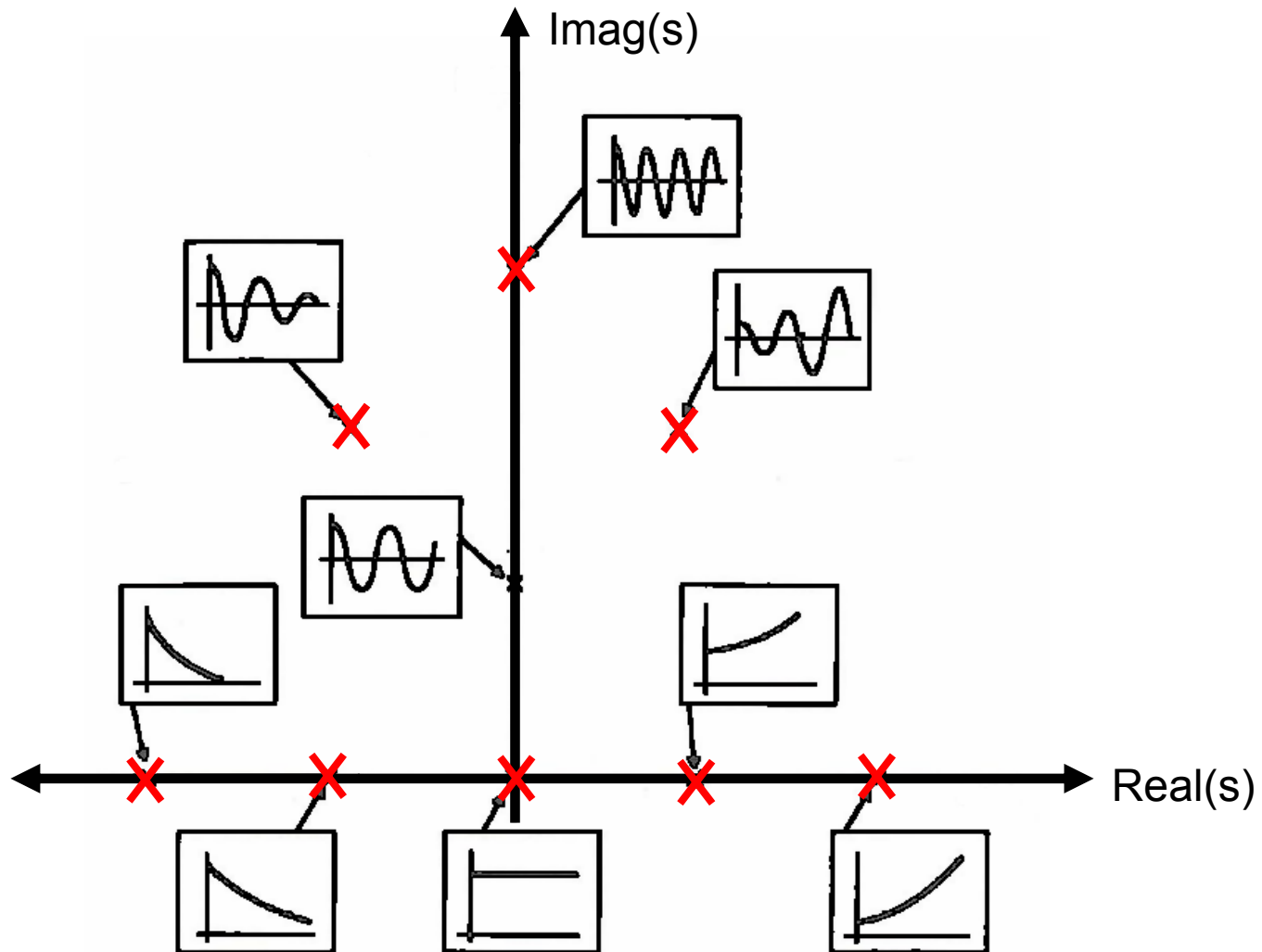
$$s^2 X(s) - 1254X(s) + 32V(s) + 466 = 0$$

Transfer Function

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

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

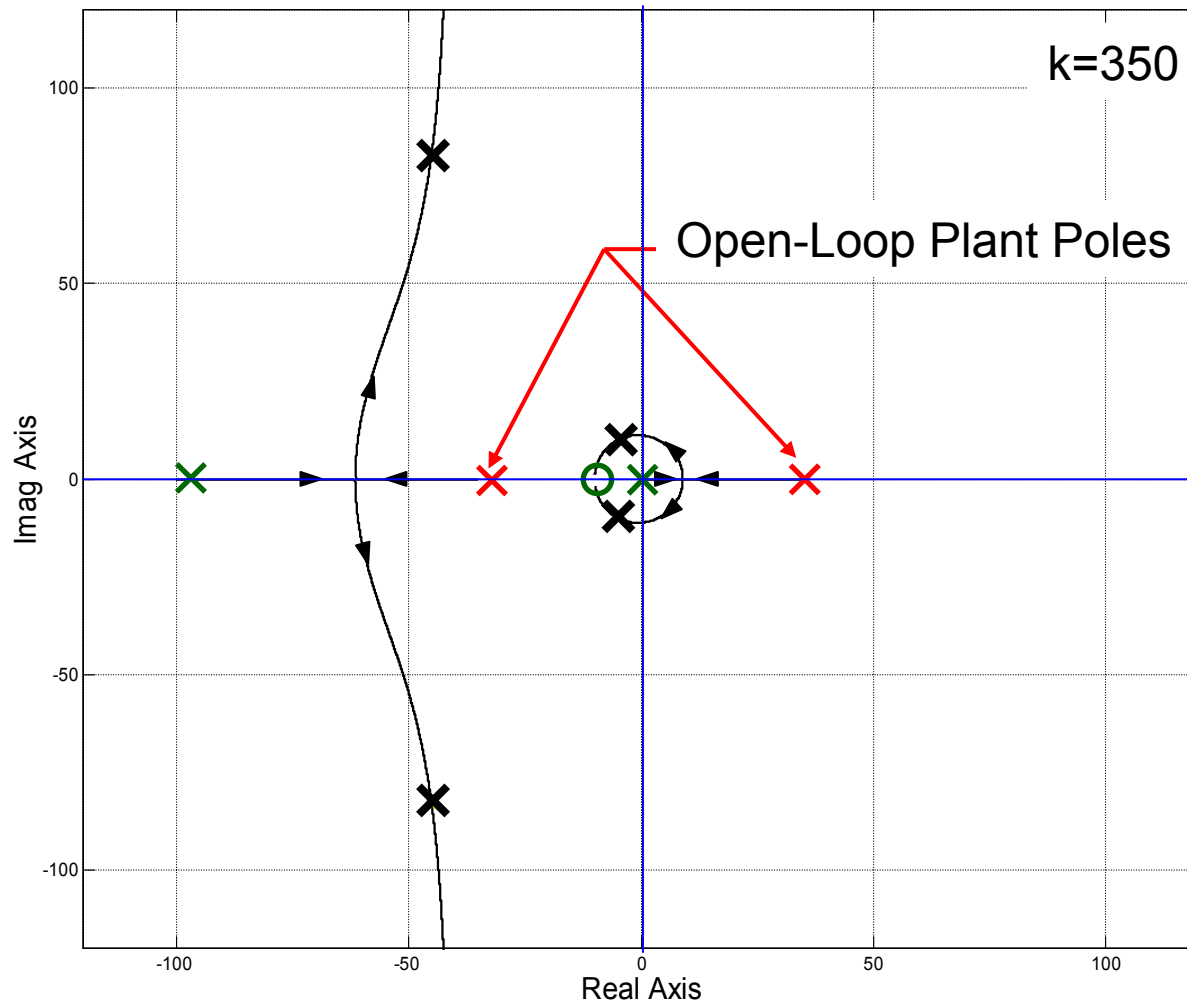
Impulse Response vs Pole Location



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

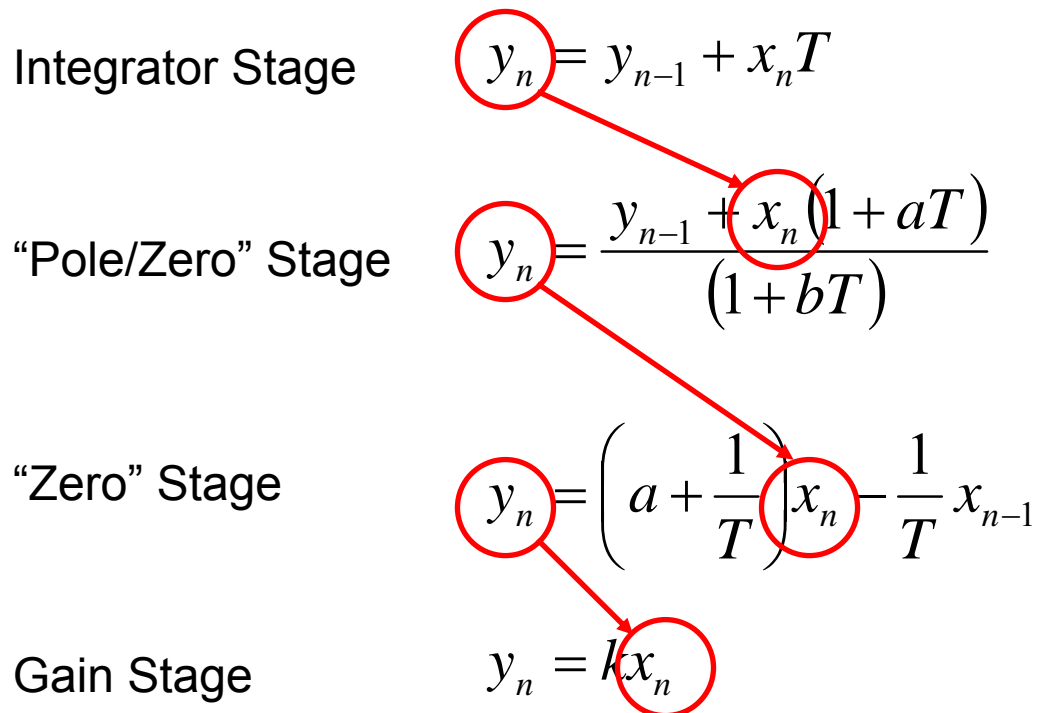


Controller Dynamics

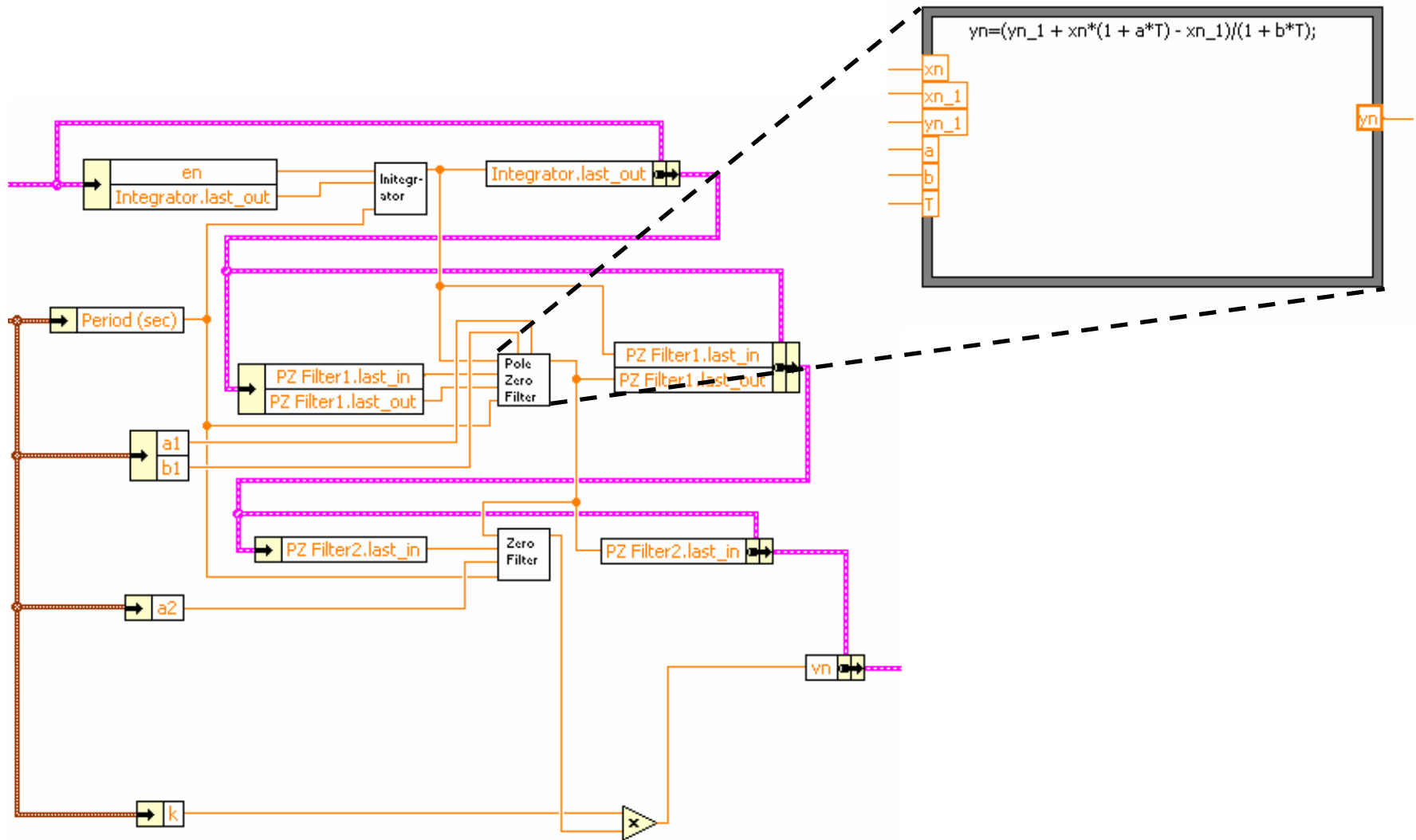
Transfer Function

$$V(s) = k \frac{(s+10)(s+10)}{s(s+100)} E(s) \quad K \approx 200 \text{ to } 700$$

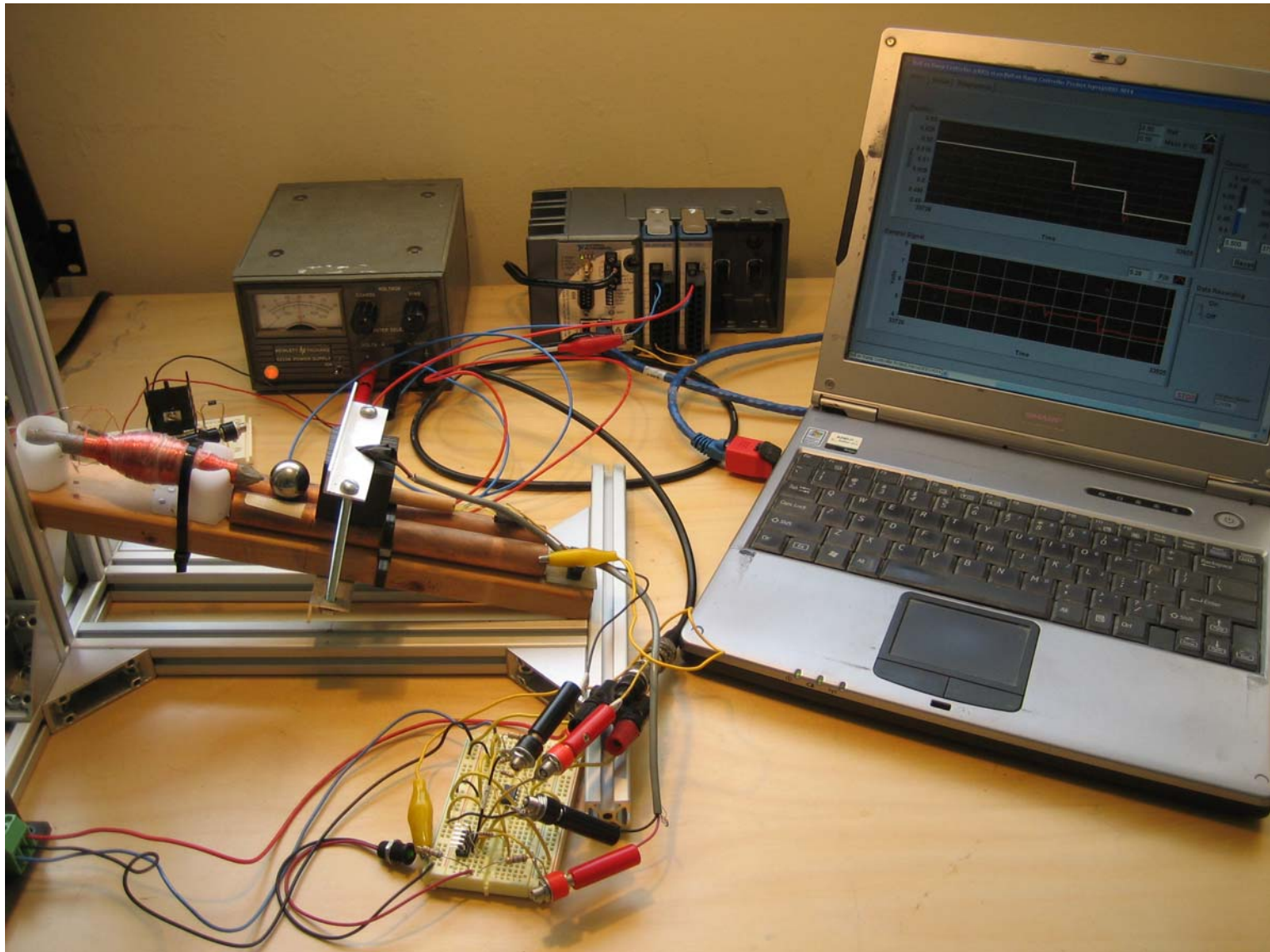
Discretized Controller Algorithm



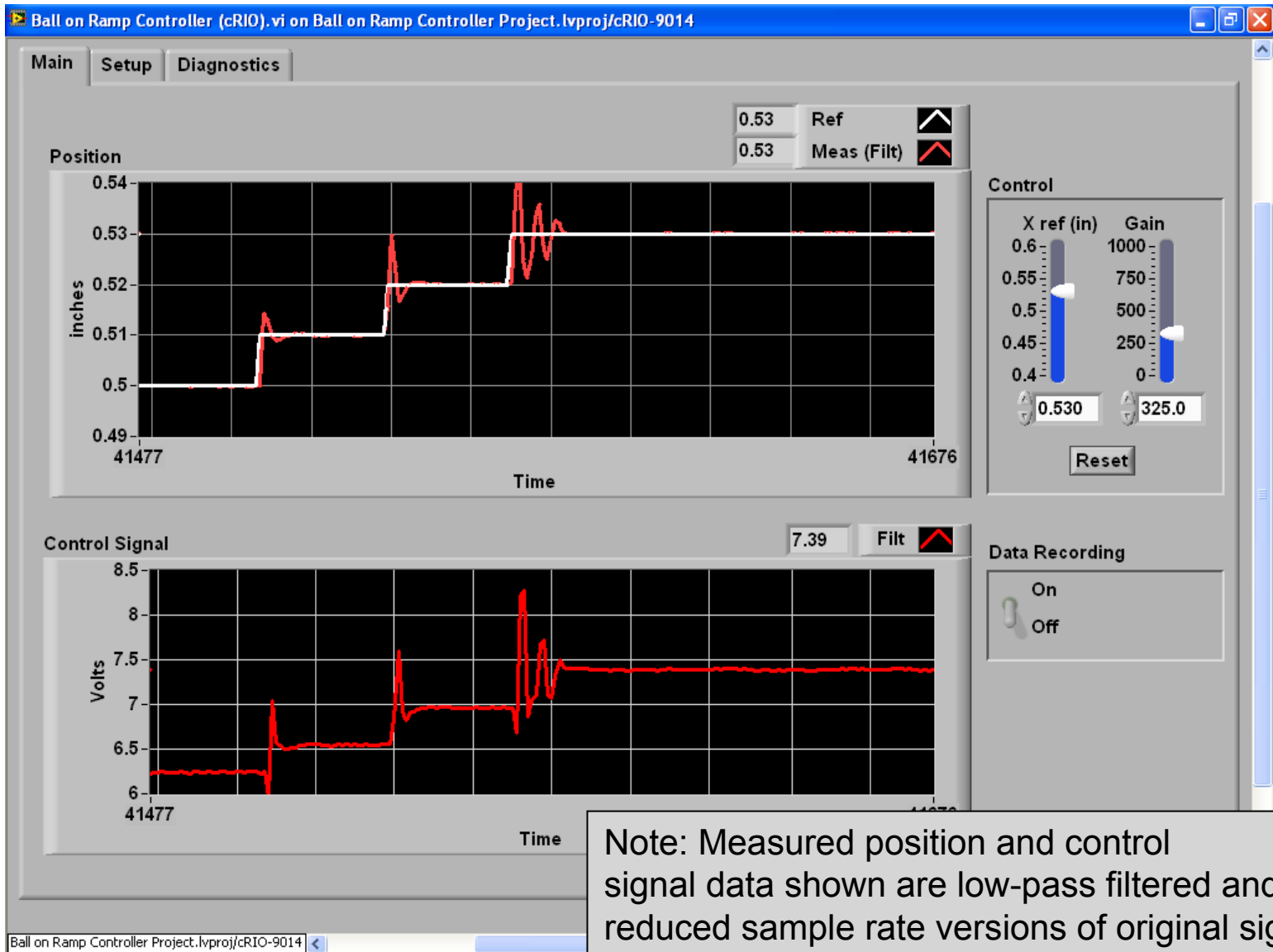
Controller Implementation in LabVIEW Real-Time



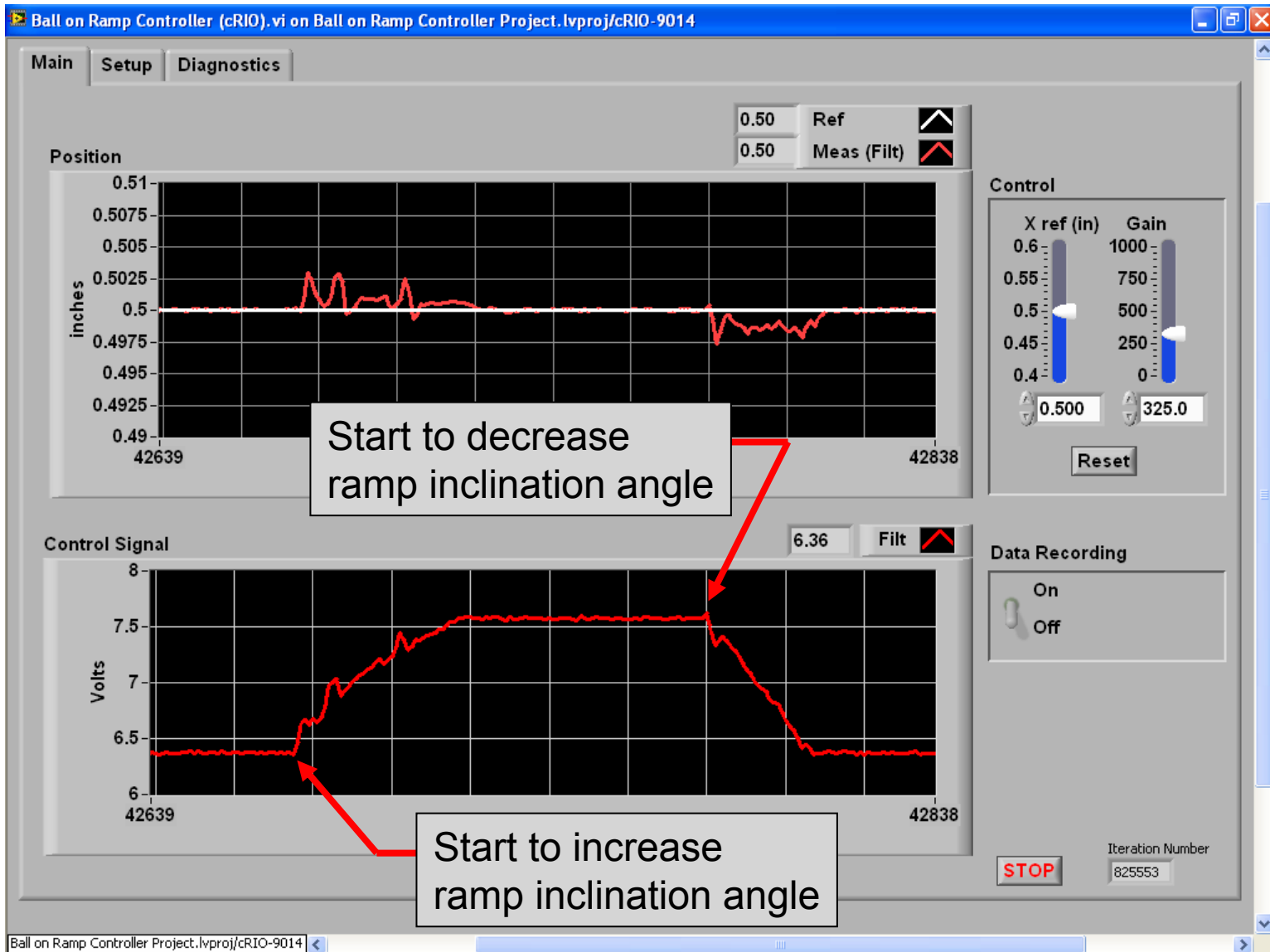
System Components



Step Response



Disturbance Rejection (Transition between $\theta=14.8^\circ$ 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	<input type="text" value="0"/>
780449-03	LabVIEW Embedded Platform Evaluation Kit 180 Days	12 - 20	\$ 1,199.00	<input type="text" value="0"/>