"Model Development and Measurements for Real-Time Systems"

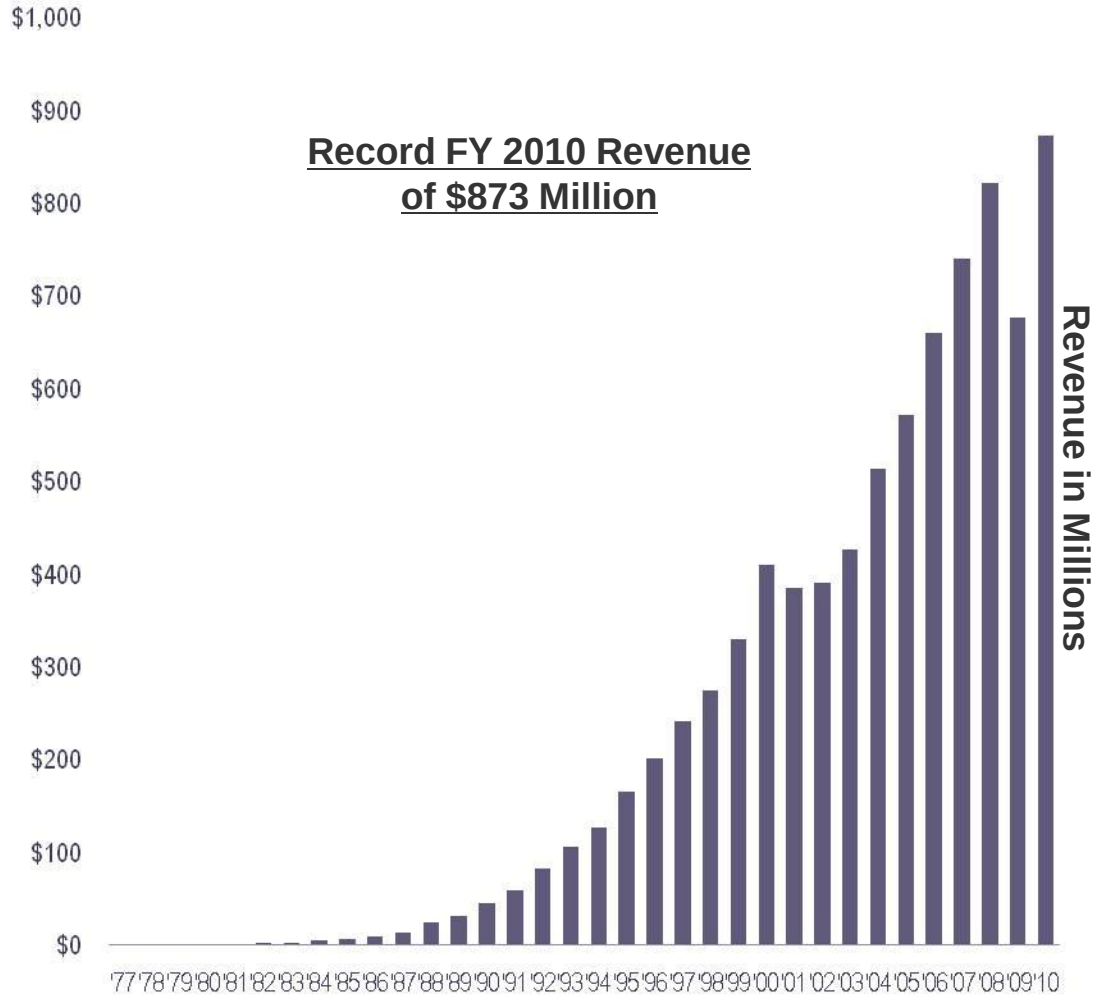
Jeannie Sullivan Falcon, Ph.D.
Chief Engineer, Control & Simulation, National Instruments

Lecturer, Mechanical Engineering & Aerospace Engineering Departments, University of Texas at Austin

National Instruments

Leader in computer-based measurement and automation

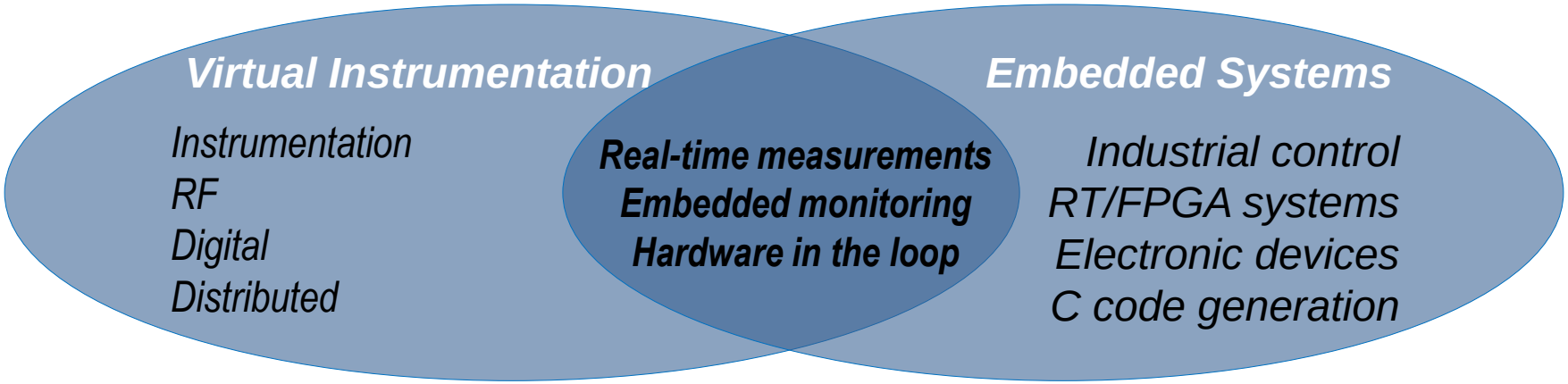
- Long-term track record of growth and profitability
- $873M revenue in 2010
- $250M revenue in Q4 2010
- More than 5,200 employees; operations in 40+ countries
- More than 30,000 companies
- No Industry >15% of Revenue
- *FORTUNE's* 100 Best Companies to Work For list for 12 consecutive years
- Cash and short-term investments of $351M at December 31, 2010



National Instruments Vision *Evolved*

"To do for embedded what the PC did for the desktop."

Graphical System Design

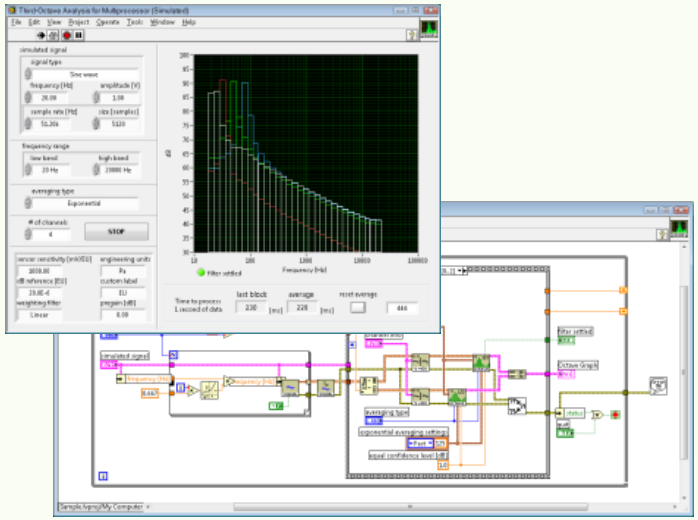


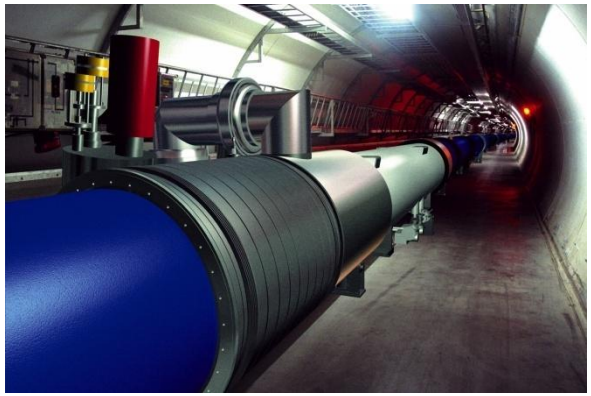
Graphical System Design

LEGO Education WeDo
"Hands-on Learning for 7 year-olds"

POWERED BY

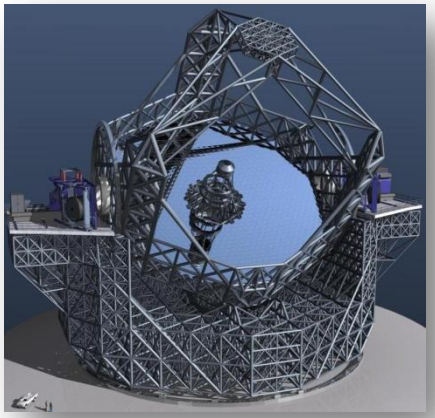
NATIONAL INSTRUMENTS LabVIEW™



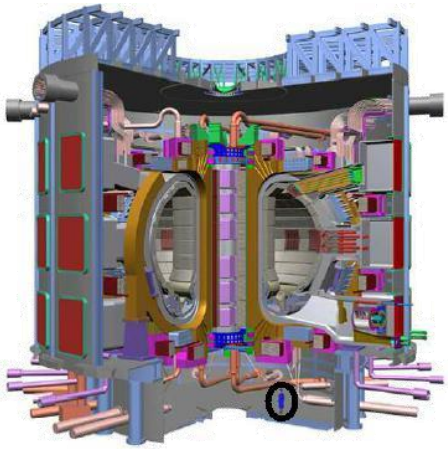


CERN Large Hadron Collider
"the most powerful instrument on earth"

Tough Real-Time Challenges

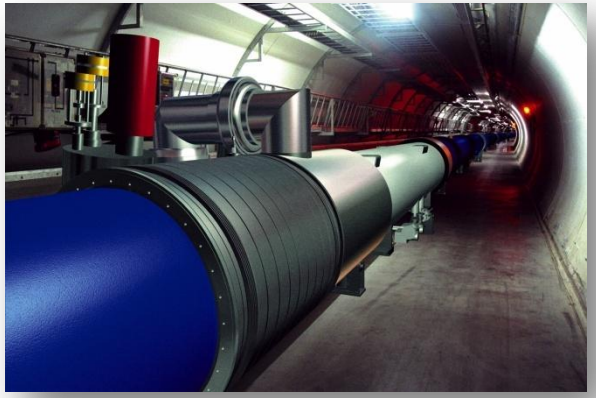


Large Telescope
Mirror Control

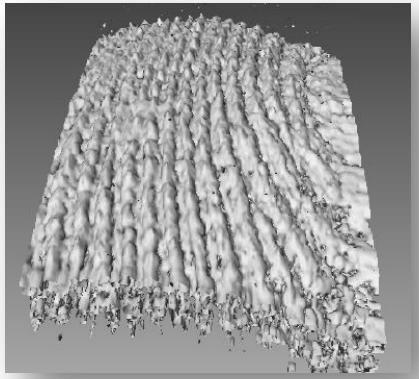


Tokomak
Plasma Control

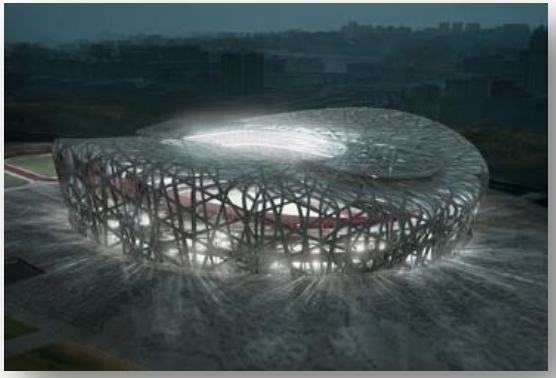
Wind Turbine Sound Source
Characterization



CERN Hadron Collider



Early Cancer Detection



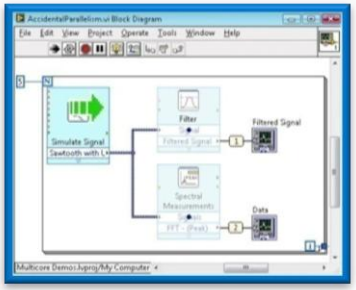
Structural Health Monitoring

Model & Measurement-Based Design

- Open software & model integration
- Multiple models of computation
- Real-time software & hardware with precision timing & I/O
- Multi-core processing
- Heterogenous architectures (RT processor/FPGA)
- Distributed measurements and computing

High-Level Design Models

Data Flow

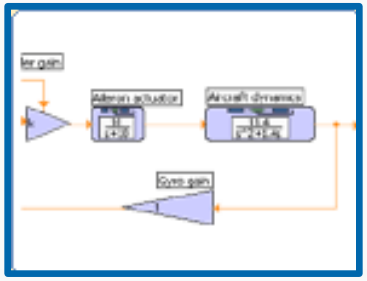


C Code

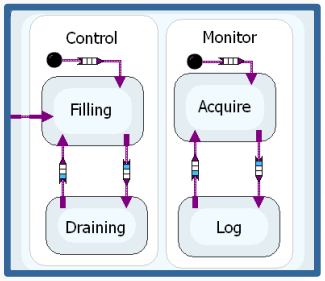
Textual Math

```
c = 0.285 + 0.013i;
[X Y] = meshgrid(x, y);
z = X + i*Y;
for k=1:30
    z = z.^2 + c;
end
```

Control & Simulation



Statechart



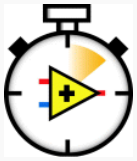
NATIONAL INSTRUMENTS

LabVIEW™

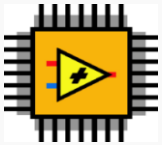
Graphical System Design Platform

Desktop

Real-Time



FPGA



Microprocessors

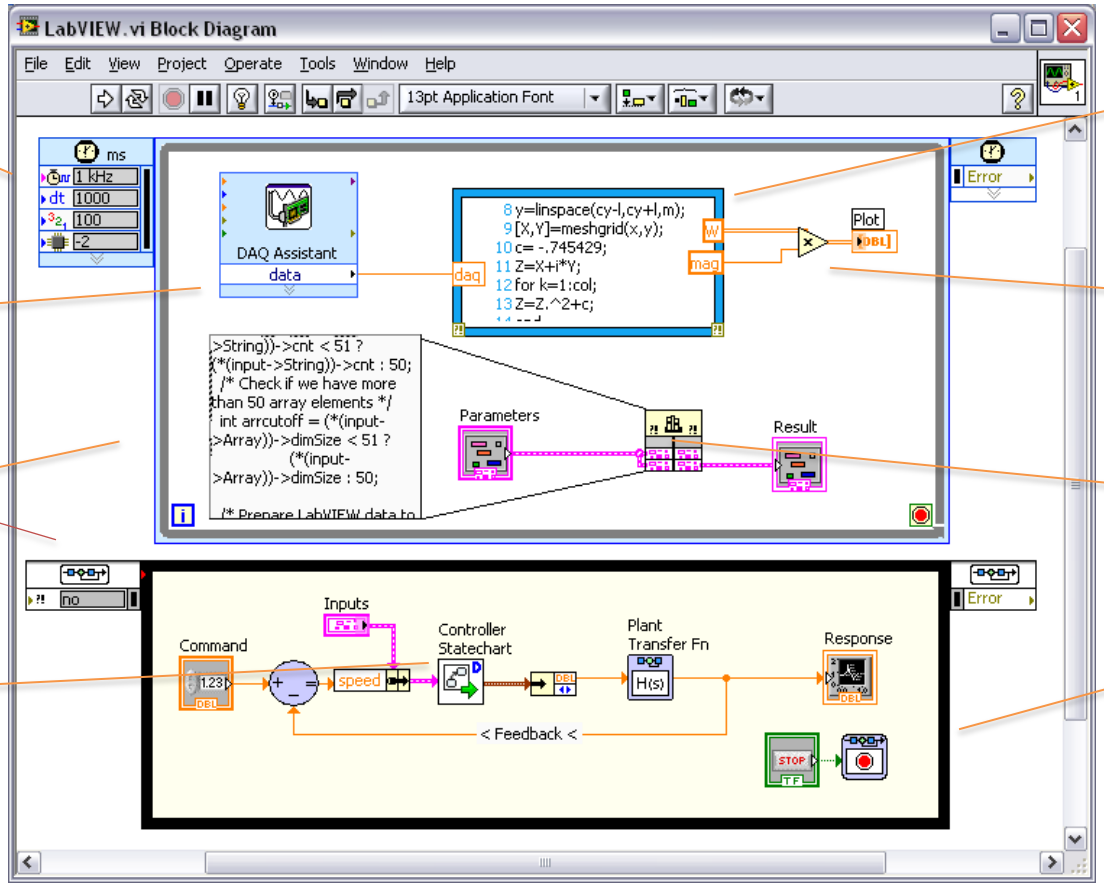
Graphical Development Environment

Timing

I/O integration

Parallel

Statecharts



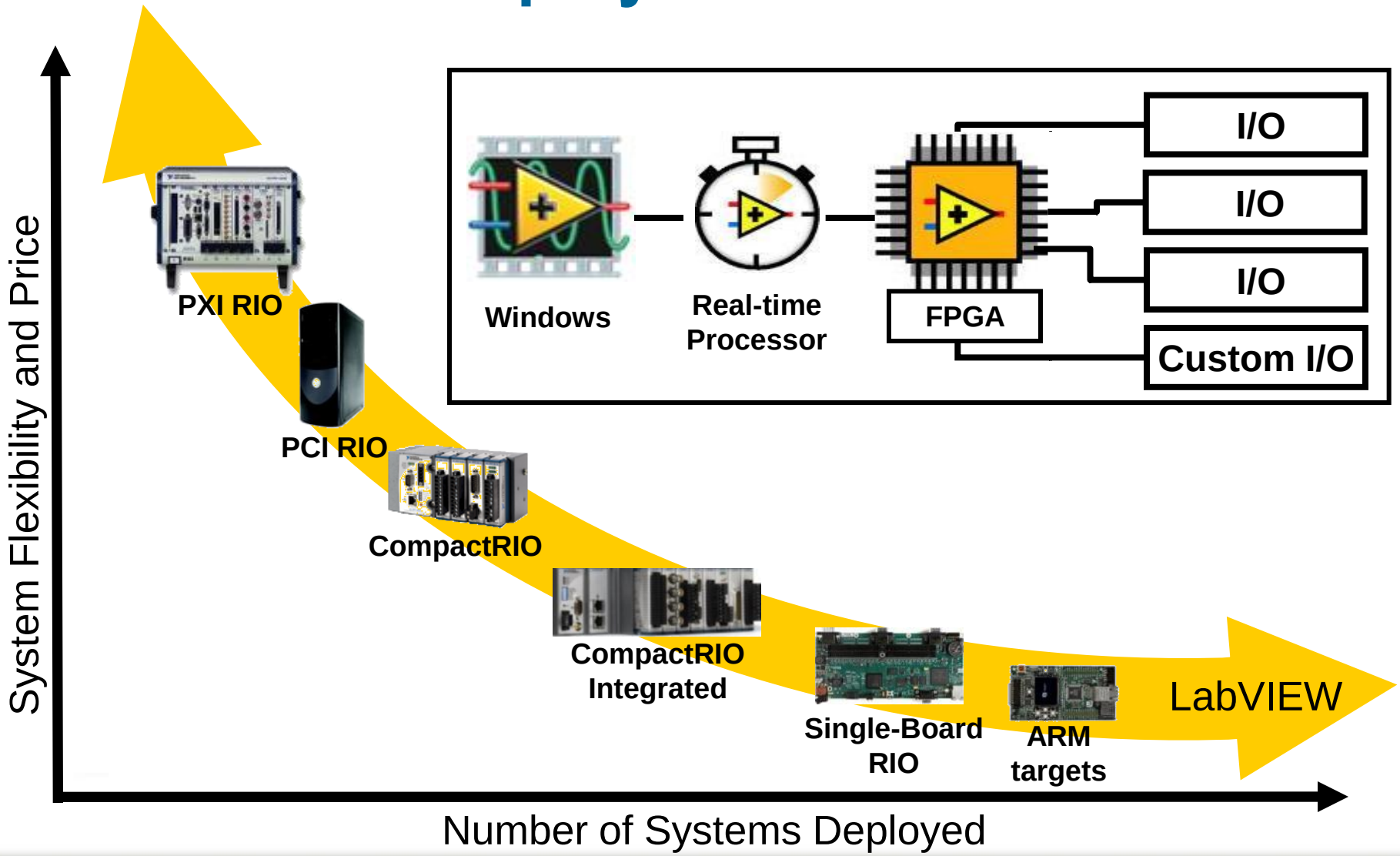
Textual Math

Data Flow

C and HDL Code

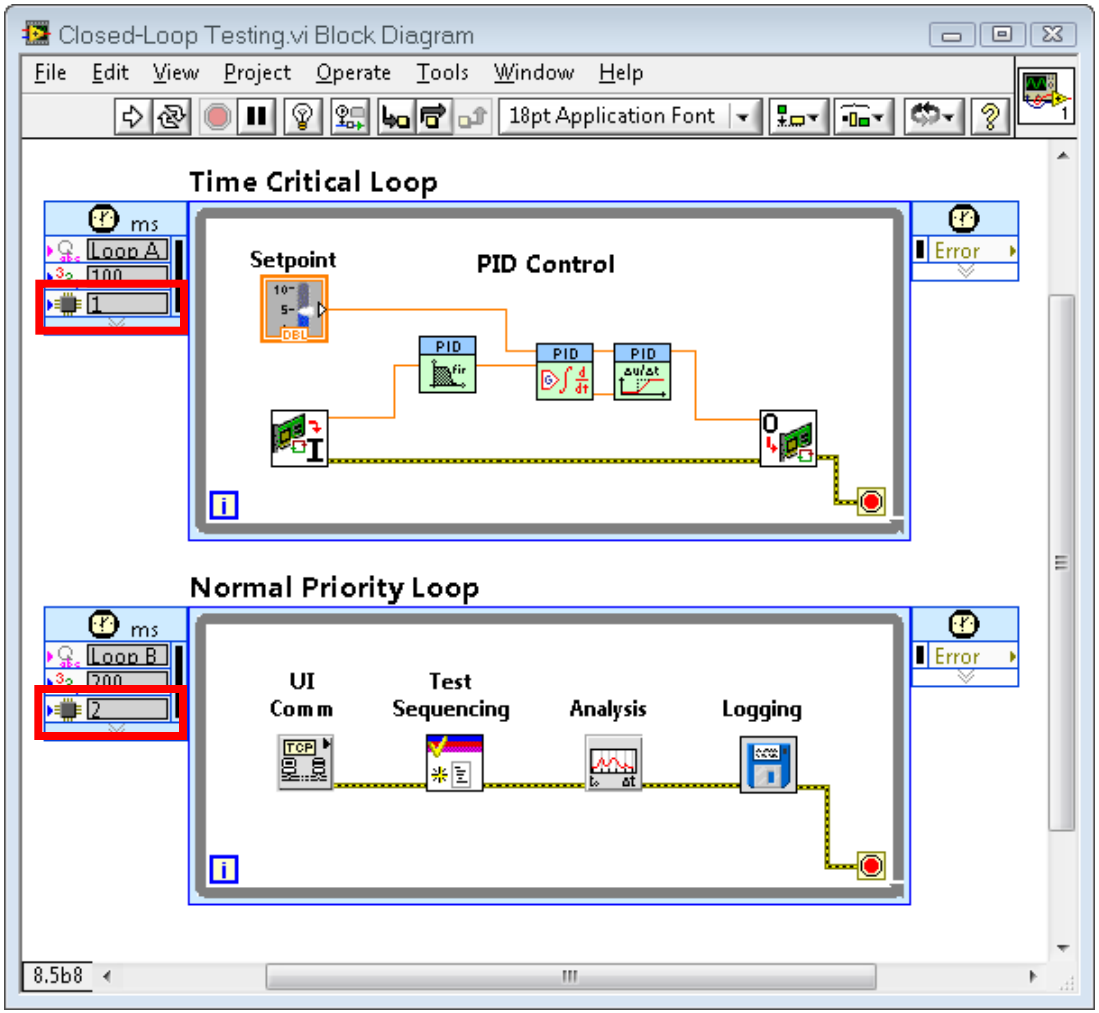
Simulation

Deployment Curve

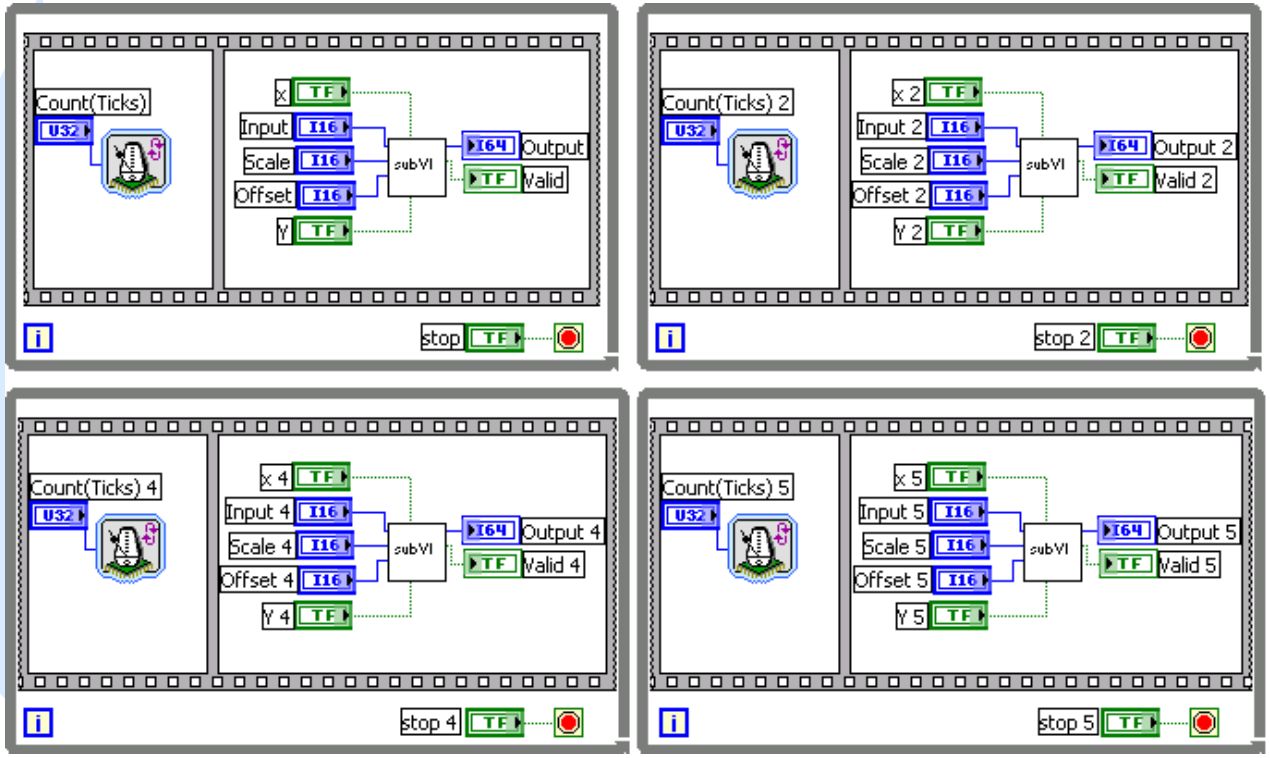


Real-Time on Multicore Processors

Assign timed loops to specific processor cores.



Field Programmable Gate Array (FPGA) Programming: The Ultimate in Multicore, Multiprocessor Development

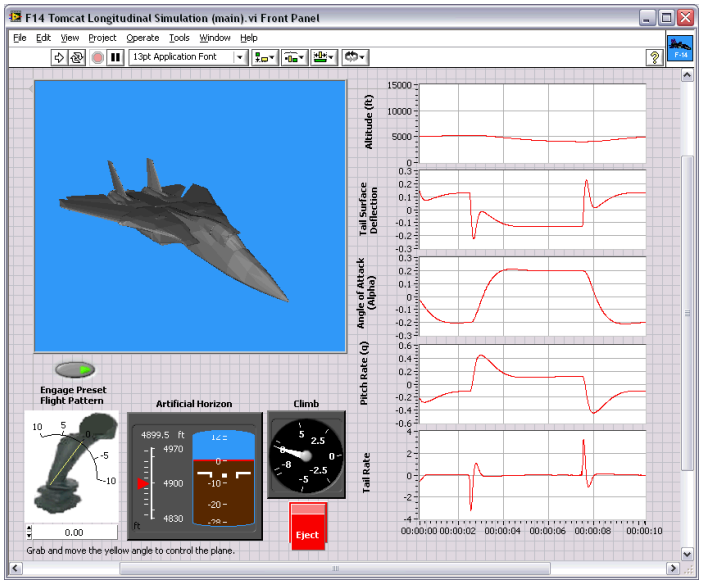


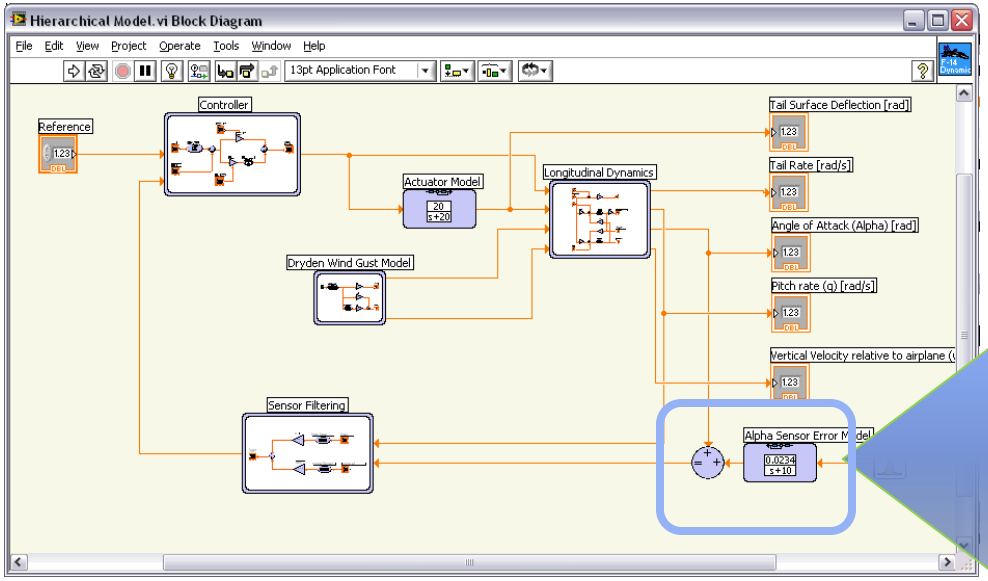
"The miracle of LabVIEW FPGA turns ideas into electronics."

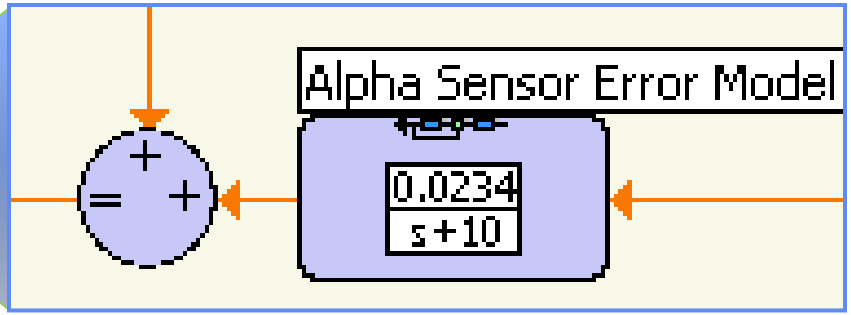
Michael Wiltberger, OptiMedica Corporation

Dynamic System Simulation & Control

- Both signal flow and .m file development
- Parallel, multi-rate, multi-core
- Single environment for:
  - Simulation of dynamic systems
  - Real-time implementation for rapid control prototyping or hardware-in-the-loop simulation

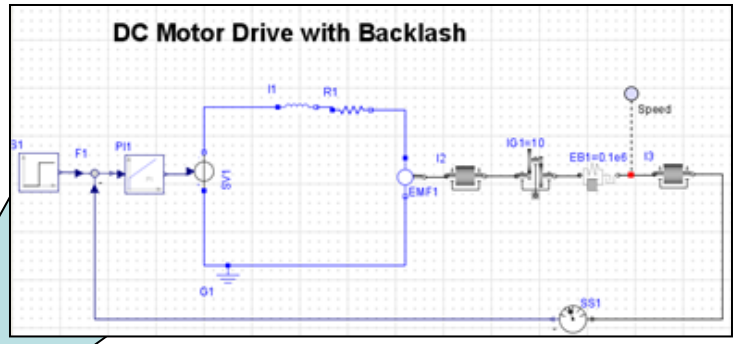


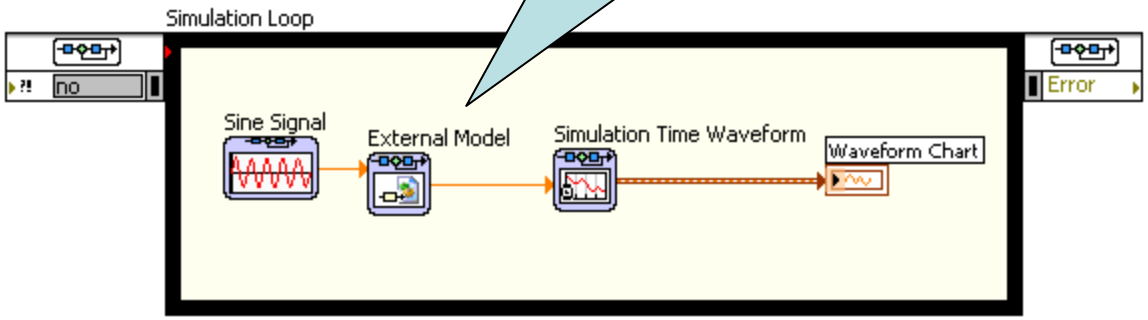




Co-Simulation w/ Multidomain Modeling Tools

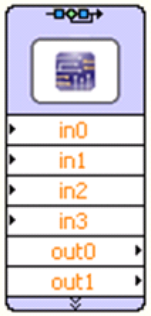
- LMS AMESim
- Dassault Systemes Dymola
- Maplesoft MapleSim
- The MathWorks, Inc. Simscape™
- ITI SimulationX

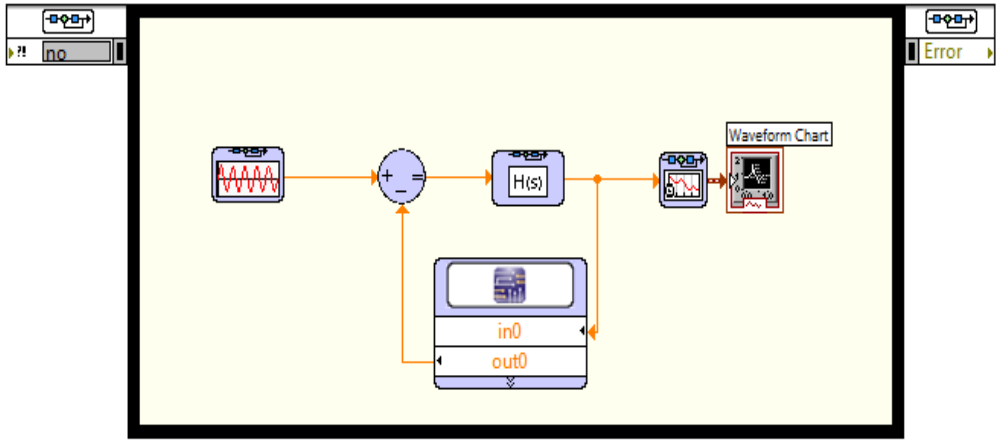




LabVIEW-Multisim Co-Simulation

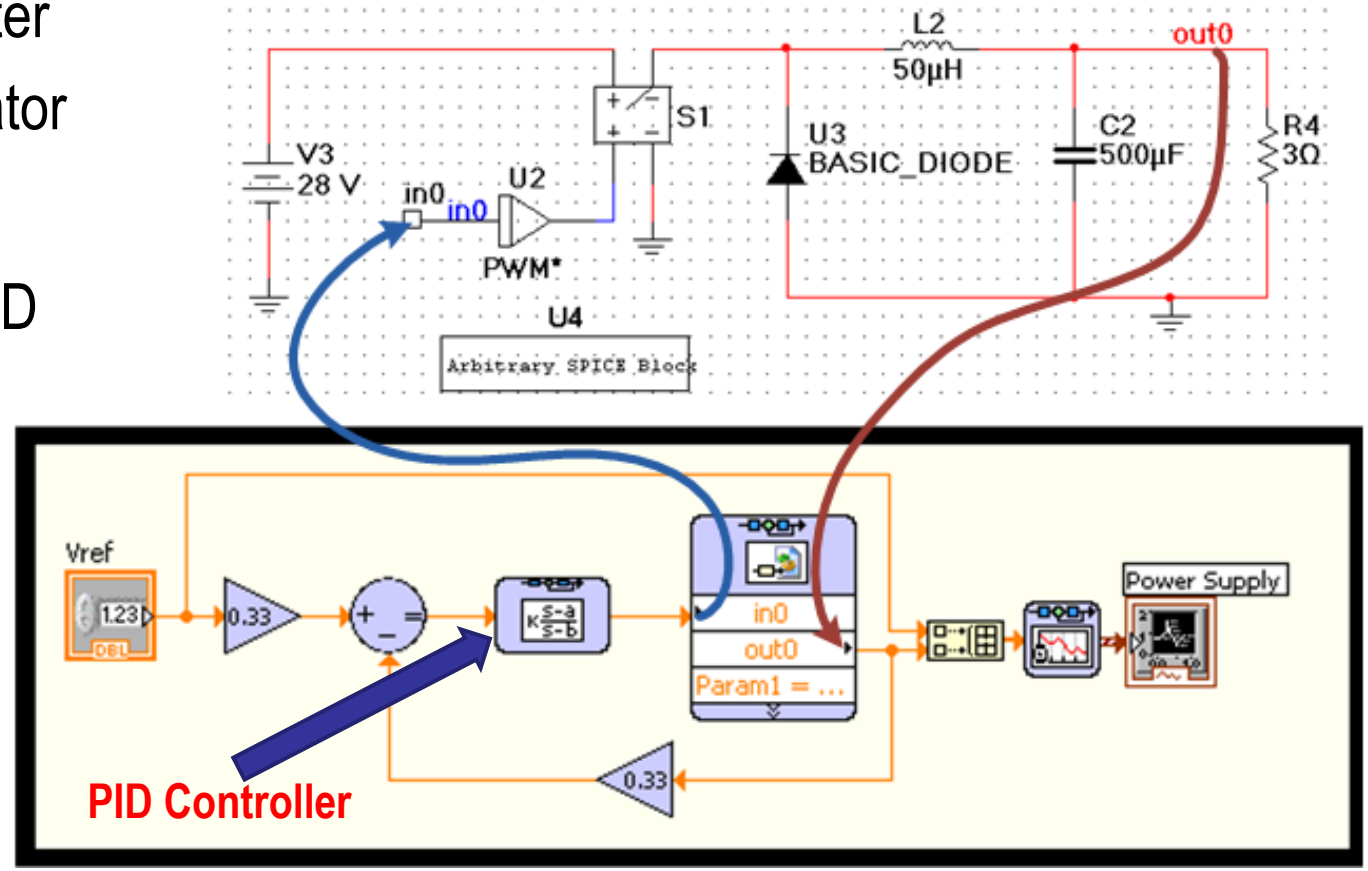
- *In development*
- Easy to use:
  - Multisim block in LabVIEW
    - Direct feedthrough type
  - Block is configurable
- Supports all solvers:
  - Fixed & variable step





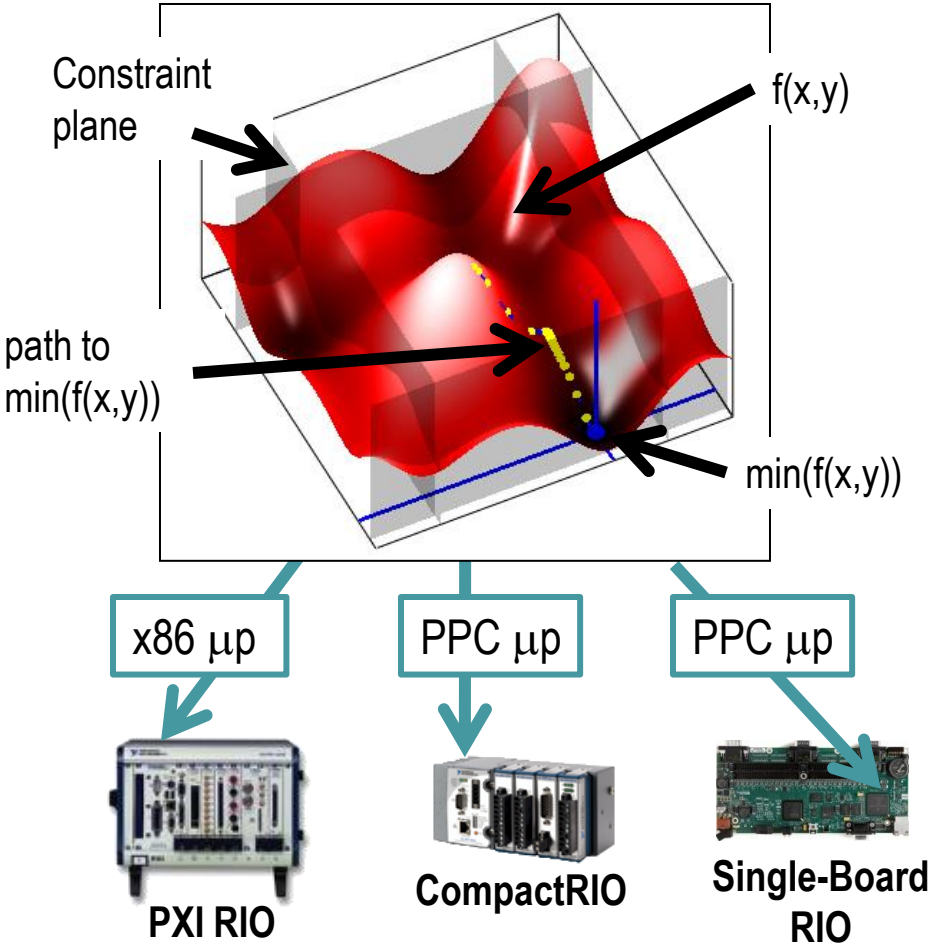
Buck Converter (Step Down DC/DC Converter)

- In Multisim:
  - Buck converter
  - PWM generator
- In LabVIEW:
  - Optimized PID controller



Real-Time Algorithms

- *Open* algorithms for microprocessor targets:
  - Optimization w/ constraints
  - Curve fitting
  - Model predictive control
  - System identification
- Solutions for MIMO & nonlinear systems
- *Online* design & adaptation



Beachhead Applications for Model & Measurement-Based Design

- Online system identification
- Hybrid hardware-in-the-loop simulation & component test
- Distributed system modeling & control
- High-speed FPGA simulation & control

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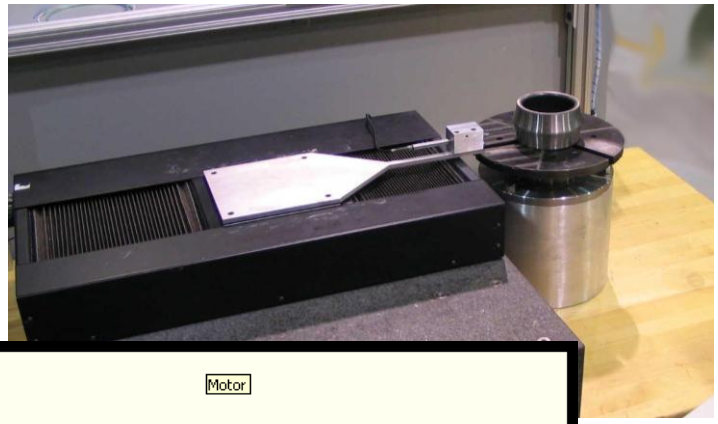
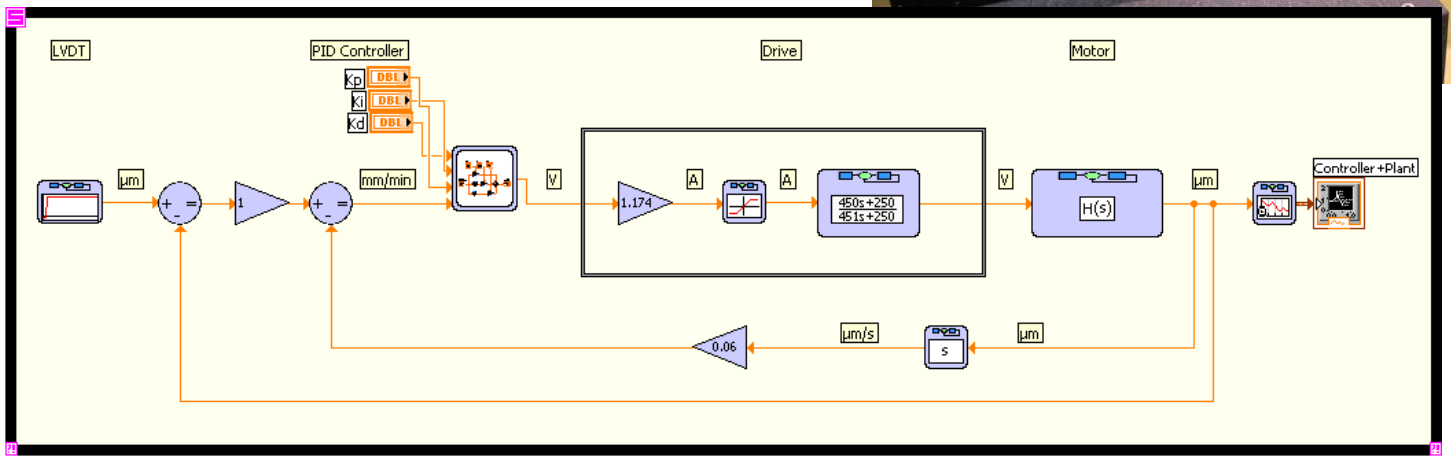
Timken - Active Bearing Centering Research

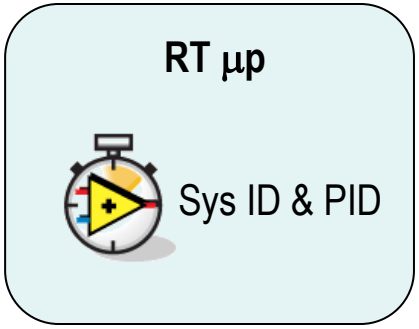
- Prof. Tom Kurfess, Prof. Laine Mears
- Real-time sliding friction identification
- Mechanical Engineering, Clemson
- LabVIEW Control Design & Simulation Module, PXI, LV-RT & FPGA

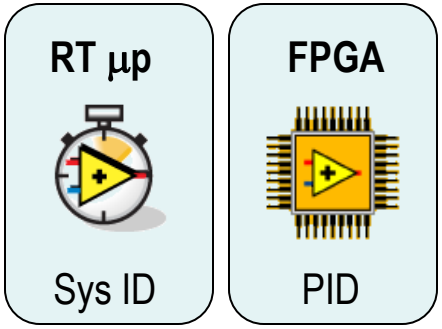




Adaptive Control Based On Real-Time System Identification

- Yaskawa linear motor with encoder and amplifier, time-varying load
- Real-time and online system identification using recursion
- Control gain table lookup based on estimated model from system ID
- Architecture options – system ID on real-time processor, control on processor or on FPGA

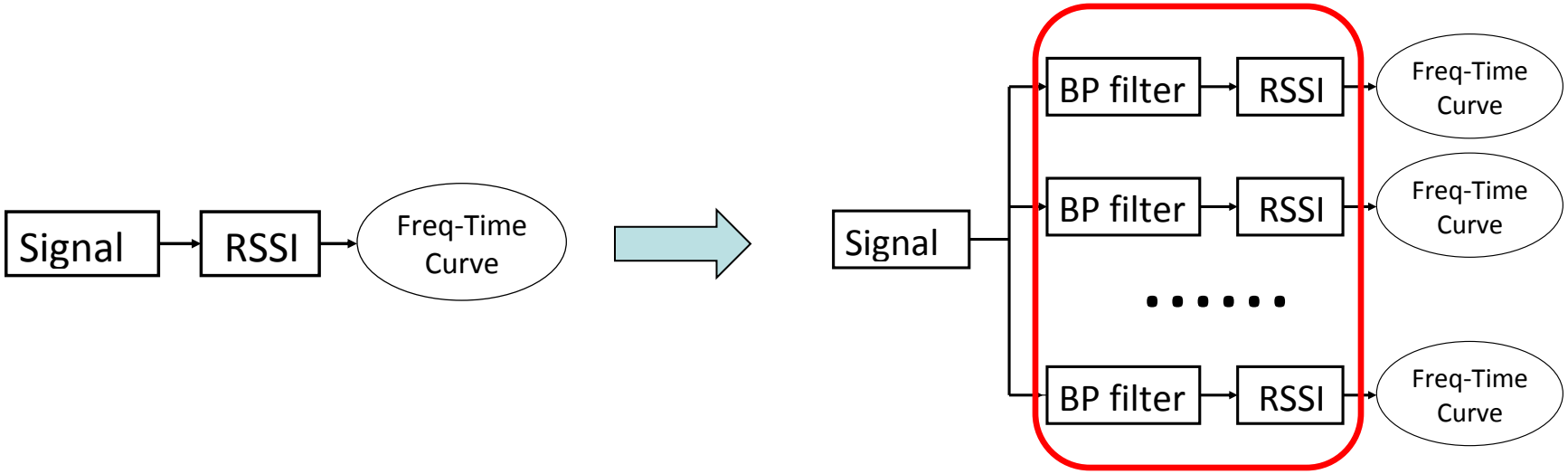




Structural Health Monitoring for Donghai Bridge in China

Multi-Core Recursive Stochastic Subspace Identification (mRSSI)

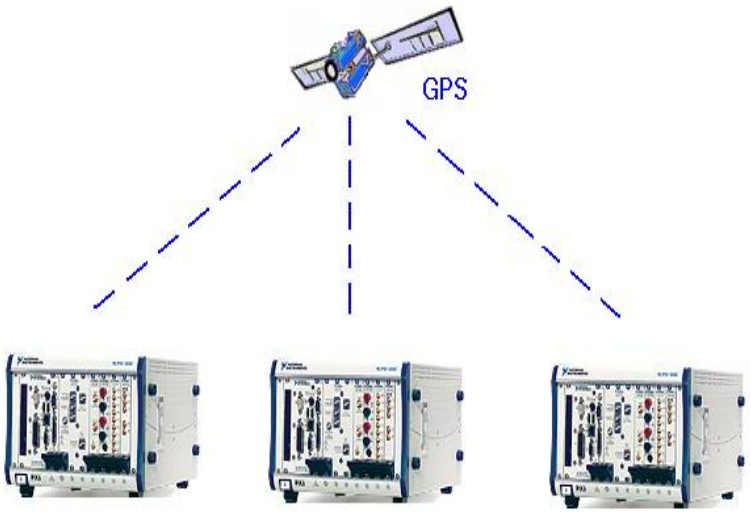
- Use band-pass filter to separate signals into sub-bands



- Leverages multi-core processor performance
- Identifies and tracks resonance frequencies

Applying mRSSI to Donghai Bridge

- 14 PXI systems for data acquisition and control
  - > 500 sensors including accelerometers, fiber Bragg grating sensors, & anemoscopes
  - GPS for system synchronization & time-stamping
- LabVIEW for mRSSI algorithm implementation



Beachhead Applications for Model & Measurement-Based Design

- Online system identification
- Hybrid hardware-in-the-loop simulation & component test
- Distributed system modeling & control
- High-speed FPGA simulation & control

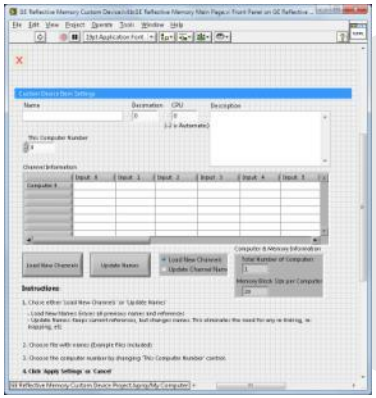
Real-Time Testing

HIL		Test Cells
Embedded Software Validation (HIL, MIL, SIL, RCP)	Model-based test cells, HIL with mechanical components	Mechanical Testing (Durability, Dyno, Environmental …)

Evolution of HIL Simulators

tecnalia
Corporación Tecnológica

NI VeriStand Framework



System Explorer

Configuration API

Real-Time Engine Configuration

Custom Device Configuration

Workspace

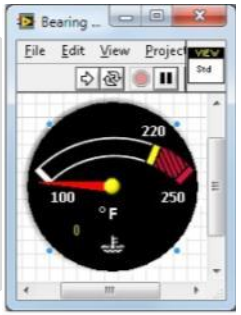
Run-Time API

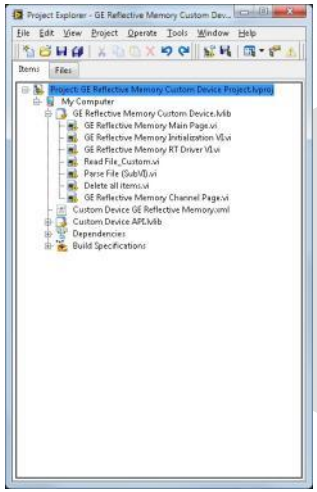
UI Objects

Run-Time Tools

Custom UI Objects

Custom Tools





NI VeriStand Real-Time Engine

I/O

Stimulus

Logging

Alarms

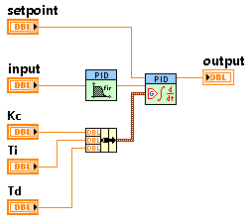
Procedures

Calculated Channels

Custom Devices

FPGA Personalities

Model DLLs



Supported Modeling Environments

Supported

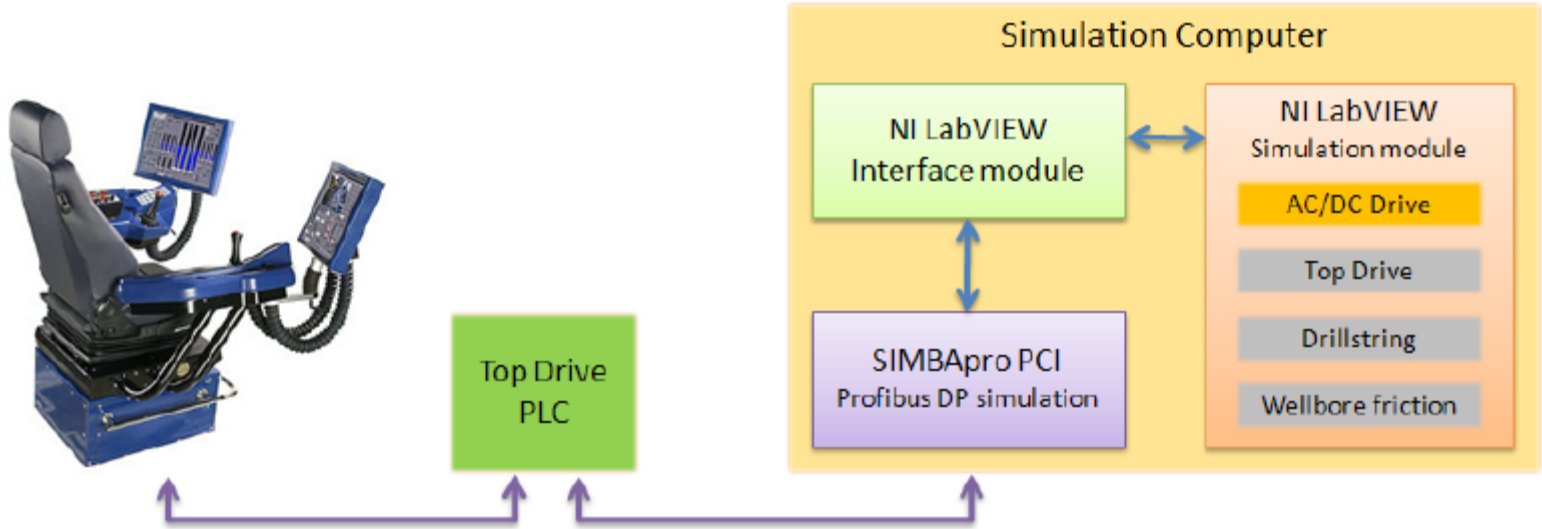
- The MathWorks, Inc. Simulink® software
- LabVIEW
- LabVIEW Control Design and Simulation Module
- MapleSim models from Maplesoft
- SimulationX from ITI
- GT-POWER engine models from Gamma Technologies Inc.
- Tesis DYNAWare models
- NI MATRIXx SystemBuild
- Esterel SCADE Suite
- C/C++/FORTRAN/Ada

In Work

- CarSim from Mechanical Simulation
- AVL BOOST/CRUISE
- WaveRT
- AMESim models from LMS
- Models from VI-grade
- Dymola models from Dynasim
- Easy5

National Oilwell Varco – HIL Simulation

- "LabVIEW supports to allocate cores to program or part of the program on **multi-core computers. This feature was used to give the simulation three cores and the interface modules one**."
- "In practice, this stage was done by **converting the Simulink models into equivalent models under the National Instruments (NI) LabVIEW environment**, which supports running a simulation in realtime."



"Hardware-In-the-Loop Simulations Used as a Cost Efficient Tool for Developing an Advanced Stick-Slip Prevention System" IADC/SPE Drilling Conference and Exhibition, February 2010

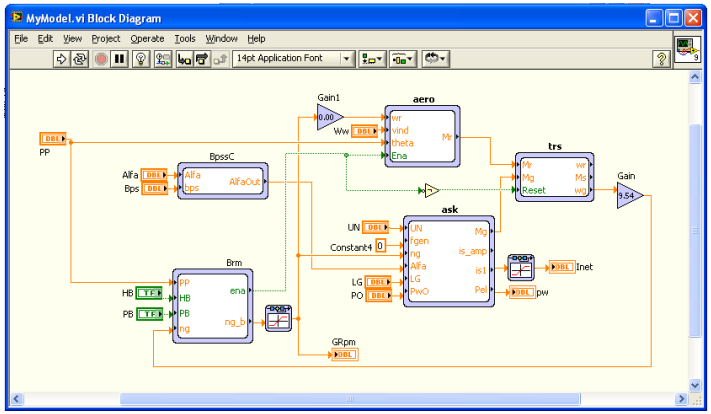
Wind turbine HIL Simulation

SIEMENS

Siemens Wind Power Denmark

- Hardware-in-the-loop (HIL) simulation of wind, pitch & blade position to test turbine controller
- Multicore PXI, LabVIEW RT & FGPA
- LabVIEW Control Design & Simulation Module

Real-time HIL model



NATIONAL INSTRUMENTS

Beachhead Applications for Model & Measurement-Based Design

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- Distributed system modeling & control
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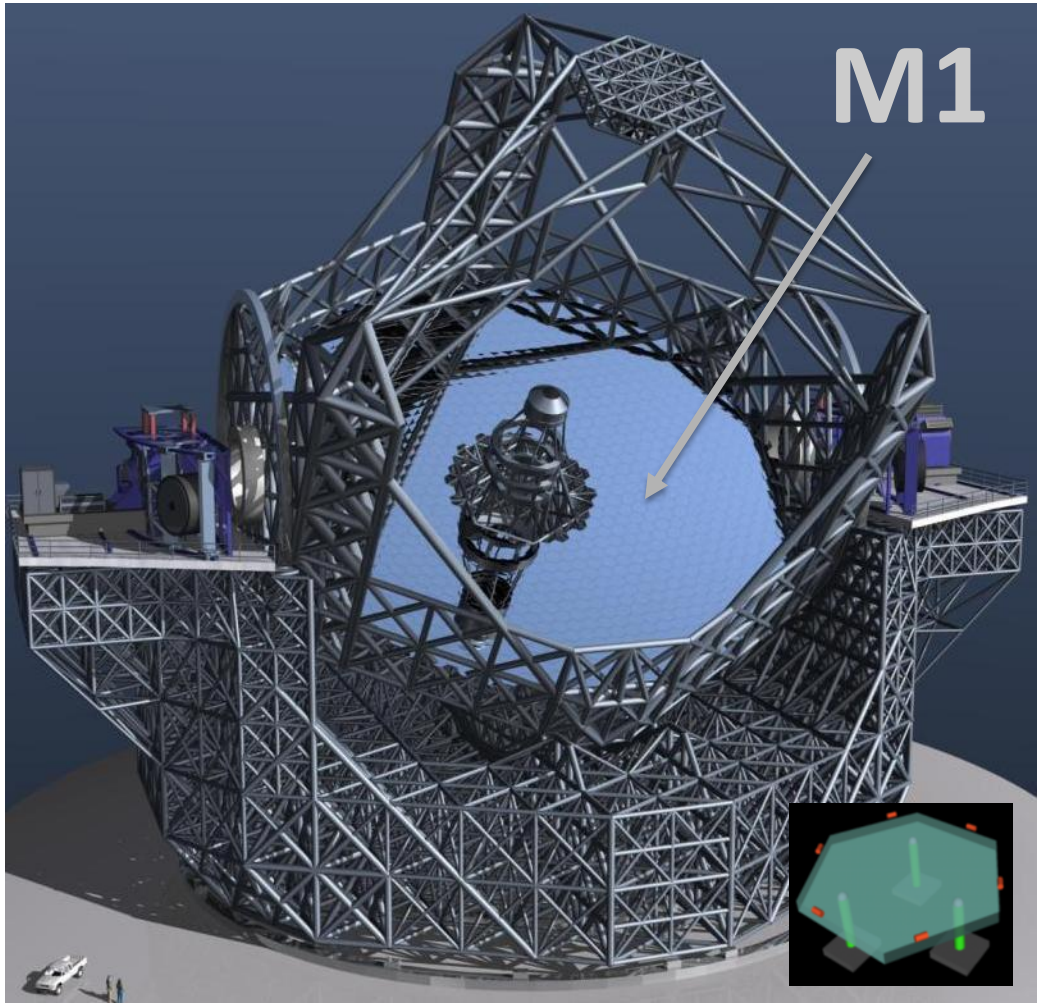
ESO - ELT – Primary Mirror (M1) Control



984 MIRRORS

3,000 ACTUATORS

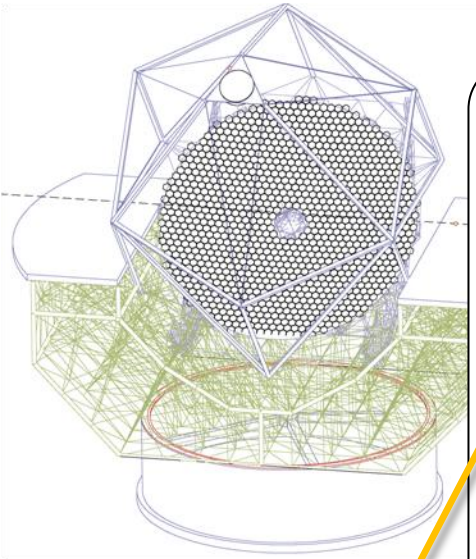
6,000 SENSORS

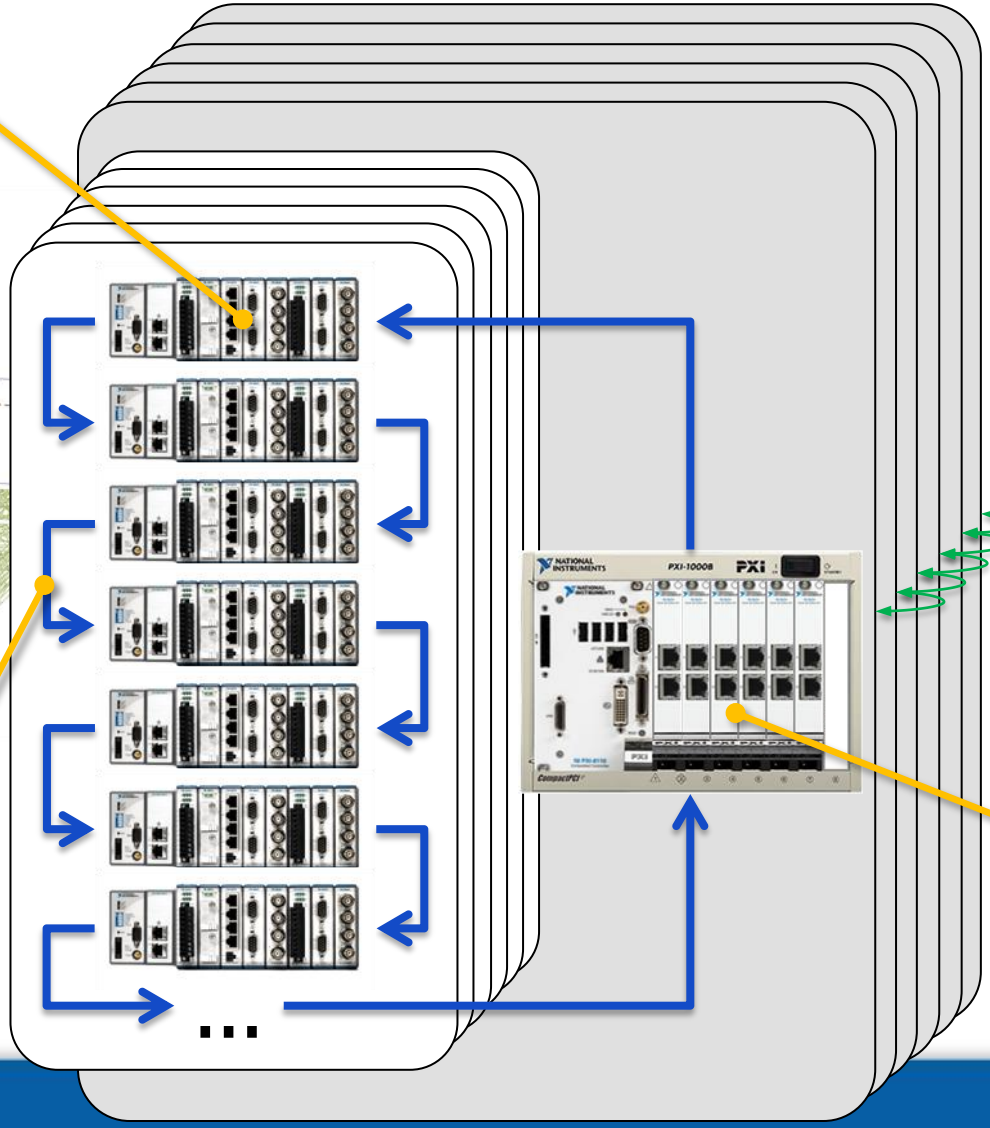
3k x 6k MATRIX

1 MILLISECOND

M1 Control Proposed System Setup

NI cRIO Node for Local Sensor / Actuator I/O
- 1 cRIO Node per Mirror





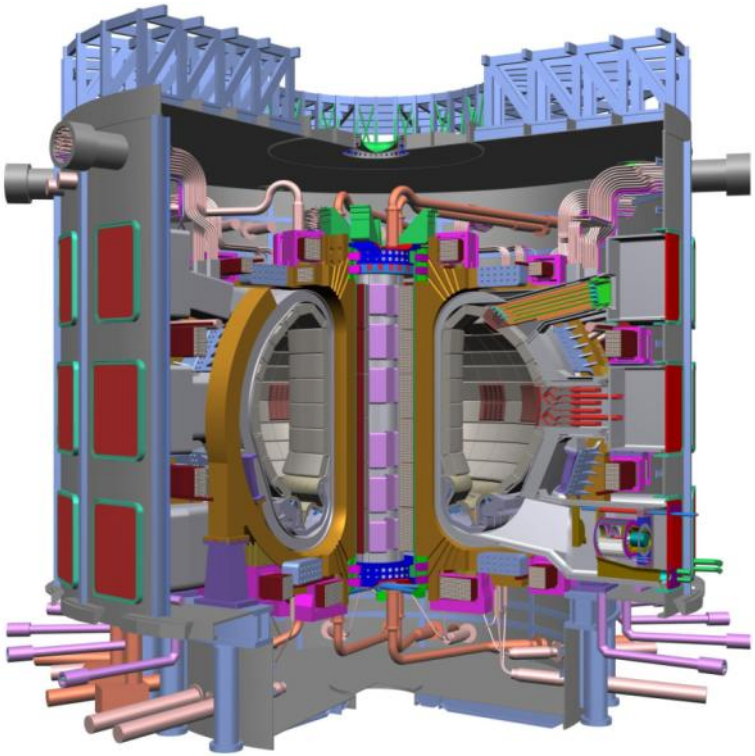
Supervisor

Supervisory Network
- 6 Distributed Mirror Controllers per Supervisor

Deterministic EtherCAT Network Ring
- 25-30 cRIO Nodes per eCAT Network Ring

NI PXI Distributed Mirror Controller
- 6 eCAT Network Rings per Distributed Mirror Controller

Tokamak – Plasma Diagnostics and Control with Multicore



- X-Ray Tomography and Plasma Control with Processing under 1 ms
- 192 Toroidal Stations
  - 512 Channels per Station
  - 10-kHz Sampling Rate per Channel
  - All Channels Synchronized

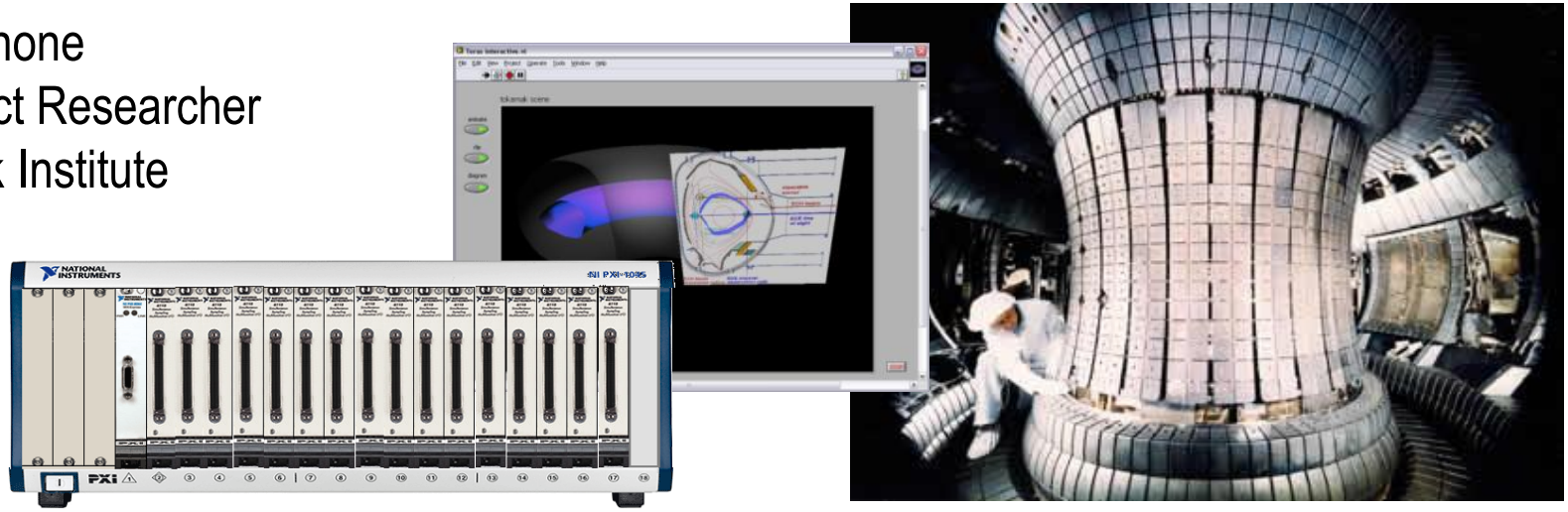
Plasma Diagnostics & Control with NI LabVIEW RT

Max-Planck-Institut für Plasmaphysik

- Max Planck Institute (Munich, Germany)
- Plasma control in nuclear fusion Tokamak with LabVIEW on an eight-core real-time system

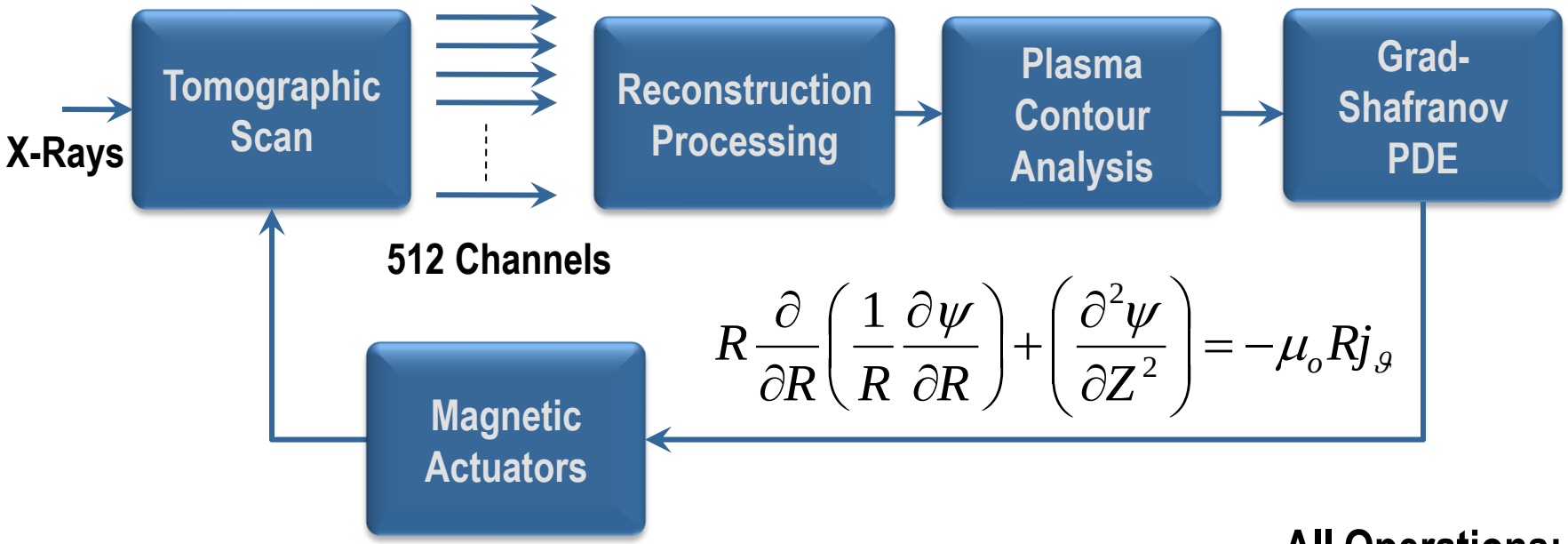
*"…with LabVIEW, we obtained a **20X processing speed-up** on an octal-core processor machine over a single-core processor…"*

Louis Giannone
Lead Project Researcher
Max Planck Institute



Next Steps:
X-Ray Tomography for Plasma Control

$$I(x,y) = B\{F^{-1}\{|f|F\{p(\tau,\theta)\}\}\}$$



$$R\frac{\partial}{\partial R}\left(\frac{1}{R}\frac{\partial\psi}{\partial R}\right)+\left(\frac{\partial^2\psi}{\partial Z^2}\right)=-\mu_o R j_\vartheta$$

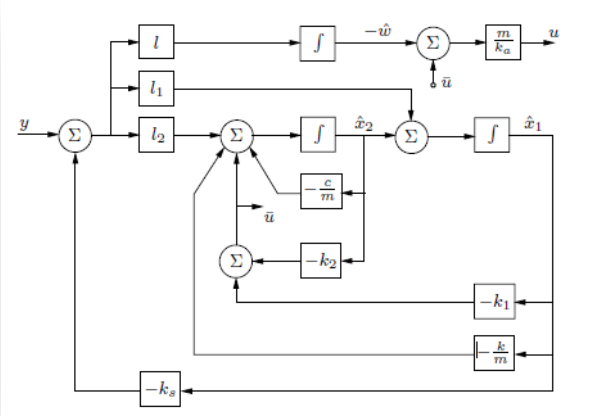
All Operations:
1 ms Loop Time
100 GFLOPs

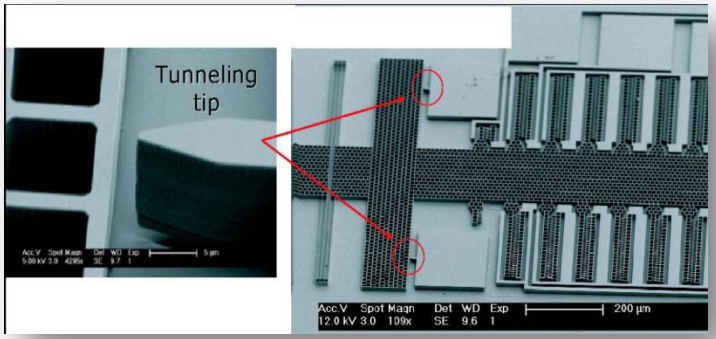
Beachhead Applications for Model & Measurement-Based Design

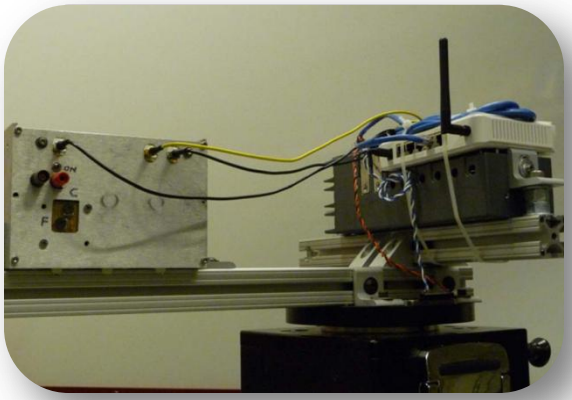
- Online system identification
- Hybrid hardware-in-the-loop simulation & component test
- Distributed system modeling & control
- High-speed FPGA simulation & control

UCSB w/ Astrom – MEMS Control

- Prof Karl Astrom (Lund) & Prof Kimberly Turner (ME) & Prof Forrest Brewer (EE)
- FPGA-based control for tunneling accelerometer (62.5 kHz loop rate)
- CompactRIO w/ wireless communication to host

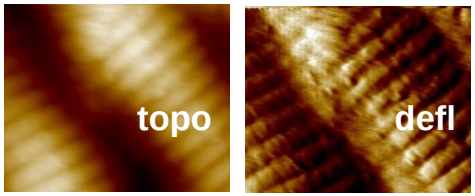






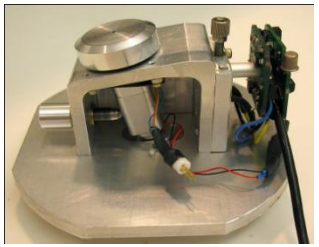
MIT - High Speed Atomic Force Microscope

- Prof Kamal Youcef-Toumi & Dan Burns, ME and Dr. Georg Fantner (now at EPFL)
- Modeling and design in LabVIEW:
  - System Identification Toolkit
  - Control Design Simulation Module
  - Digital Filter Design Toolkit
- Control implementation w/ LabVIEW FPGA:
  - Filtering & input loop shaping (200 kHz) on CompactRIO
  - Feedback controller (500 kHz) on PXI RIO device

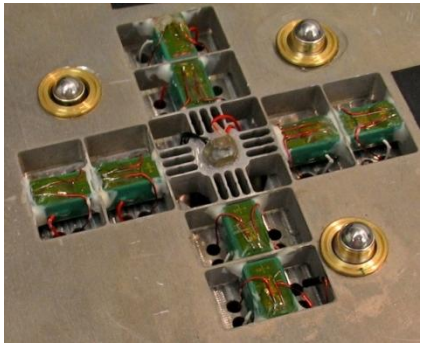


small cantilevers

custom optics head



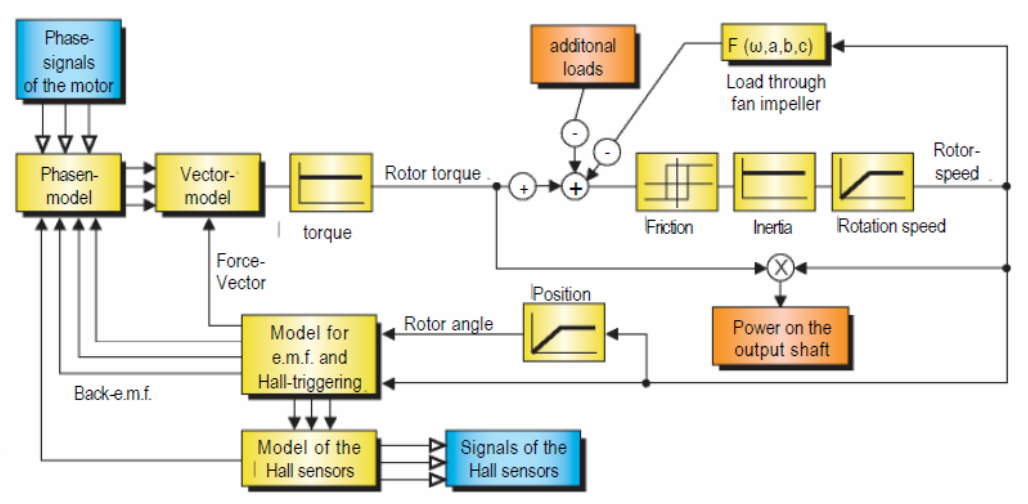
custom sample scanner



Real-Time HIL Testing- SET GmbH

Real-Time Power Simulators for HIL Testing of Drives/Inverters

- Real-time simulation as a substitute for mechanical test benches
- Enables comprehensive automated testing, including fault scenarios
- NI LabVIEW FPGA, NI Reconfigurable I/O hardware, High Performance Real-Time Power Simulators

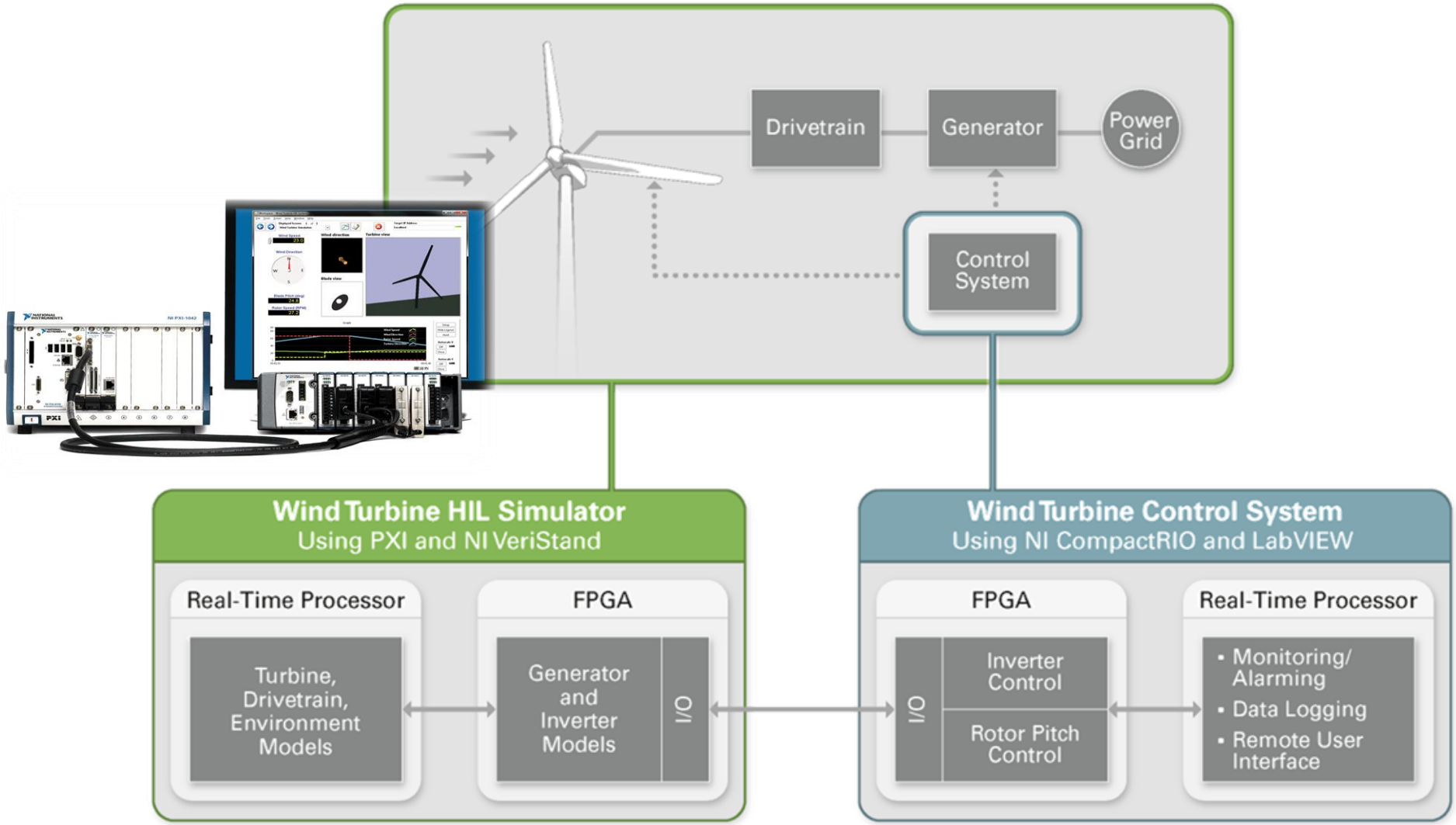


Real-Time "Virtual Motor" Simulator

Education

FPGA-based Real-Time Wind Turbine HIL Simulation

Proof of Concept

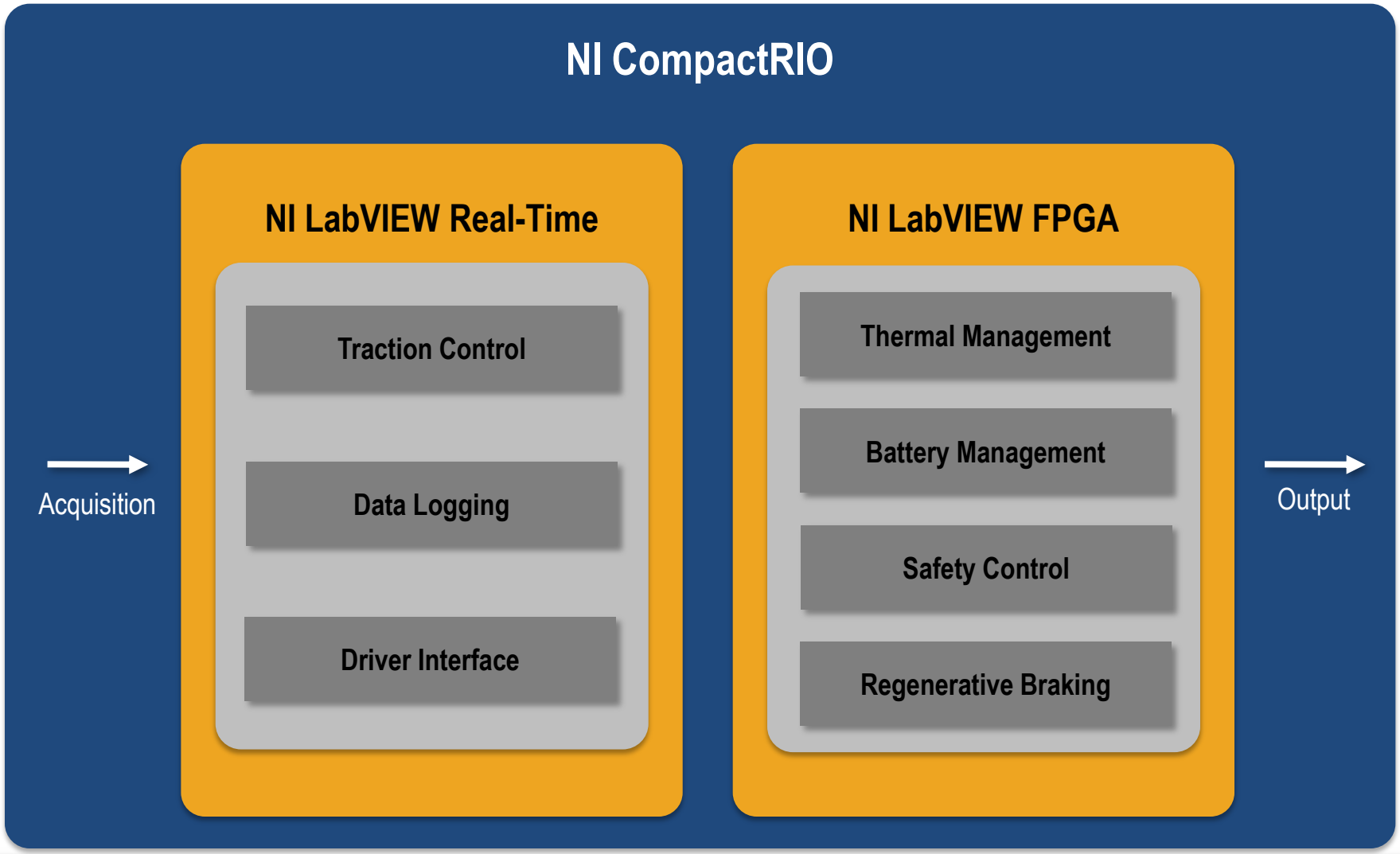


NIWeek 2009 Keynote Demo Video with NI VeriStand

Imperial College London – Student Design Team

- Racing Green Endurance – from Alaska to Argentina (16,000 miles) in an electric sports car
- Undergraduate teaching project involving almost 100 students across 8 engineering departments
- Teams build low emissions, hydrogen fuel cell, and battery electric vehicles

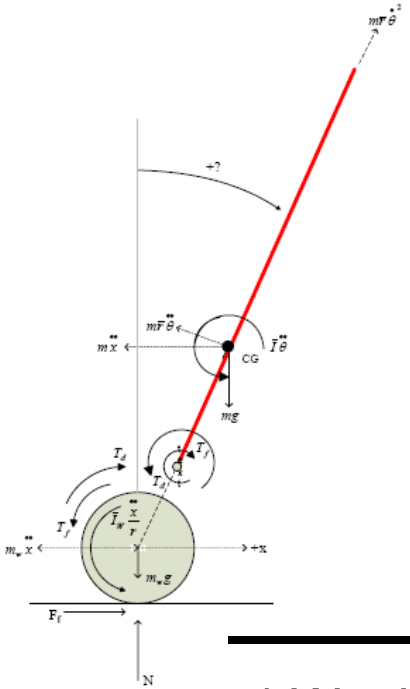
Imperial College – Racing Green Endurance

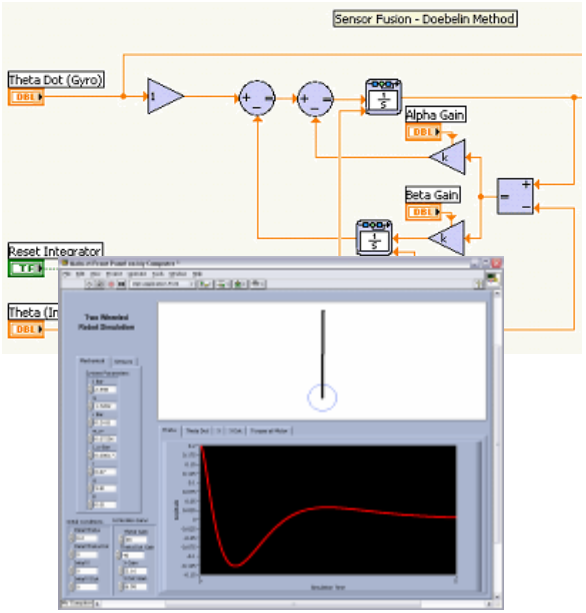


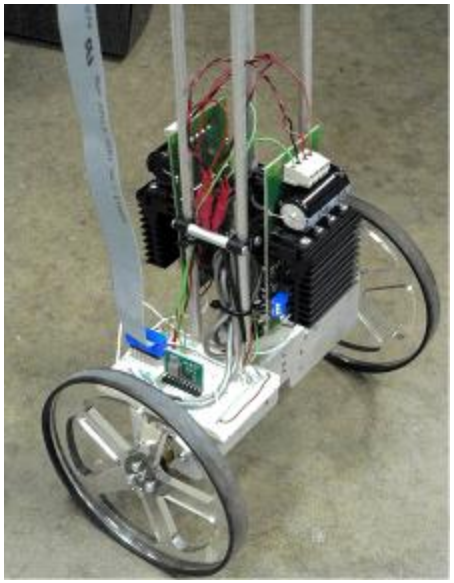
Multidisciplinary Teamwork Projects

Rensselaer Polytechnic Institute : HOT-V

Theory | **Design** | **Prototype** | **Deploy**



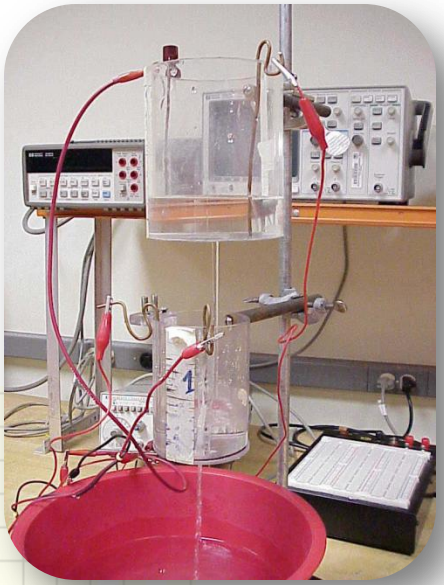


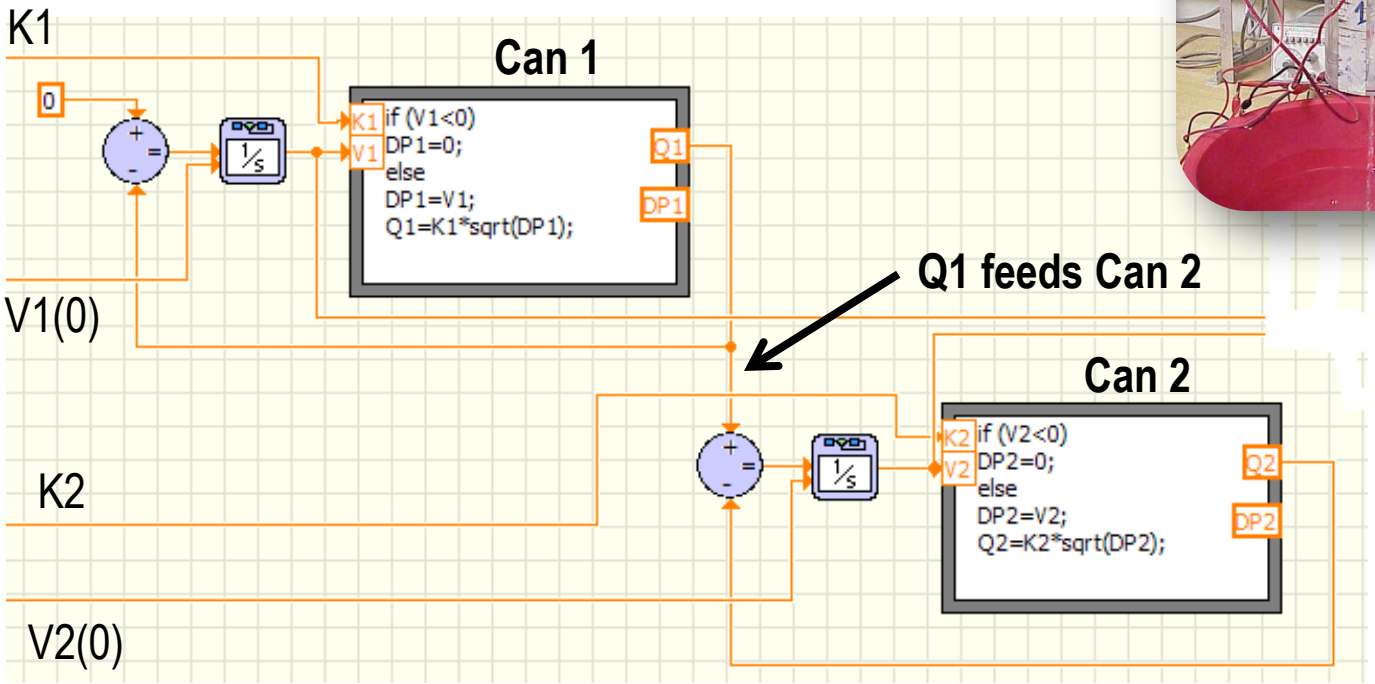


4 Weeks → 8 Weeks → 1 Week

UT-Austin – Dynamic Systems & Controls Lab (U)

- Prof. Raul Longoria, ME
- Example - two can simulation
- Formula node used to:
  - Check for negative dynamic volume (V) condition
  - Calculate orifice flow rate (Q)





Model & Measurement-Based Design

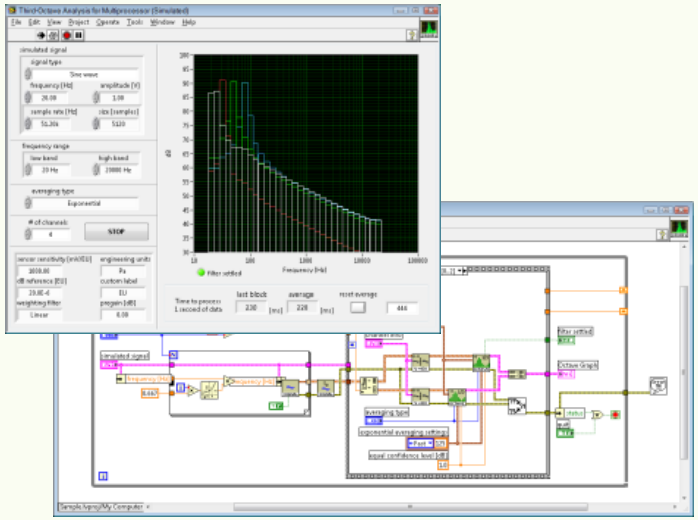
- Open software & model integration
- Multiple models of computation
- Real-time software & hardware with precision timing & I/O
- Multi-core processing
- Heterogenous architectures (RT processors/FPGA)
- Distributed measurement and computing

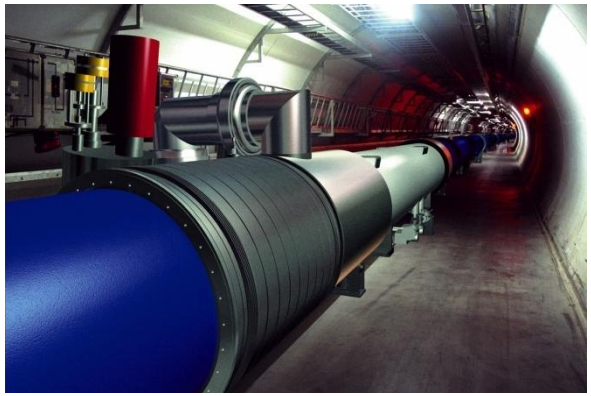
Graphical System Design

LEGO Education WeDo
"Hands-on Learning for 7 year-olds"

POWERED BY

NATIONAL INSTRUMENTS LabVIEW™





CERN Large Hadron Collider
"the most powerful instrument on earth"