“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

Virtual Instrumentation
- Instrumentation
- RF
- Digital
- Distributed

Embedded Systems
- Industrial control
- RT/FPGA systems
- Electronic devices
- C code generation

Real-time measurements
Embedded monitoring
Hardware in the loop

DESIGN  PROTOTYPE  DEPLOY

ni.com
Graphical System Design

LEGO Education WeDo
“Hands-on Learning for 7 year-olds”

CERN Large Hadron Collider
“the most powerful instrument on earth”

ni.com
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

ni.com
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

Control & Simulation

Statechart

LabVIEW™
Graphical System Design Platform

Desktop
Real-Time
FPGA
Microprocessors

ni.com
Graphical Development Environment

- Timing
- I/O integration
- Parallel
- Statecharts
- Textual Math
- Data Flow
- C and HDL Code
- Simulation
Deployment Curve

- PXI RIO
- PCI RIO
- CompactRIO
- CompactRIO Integrated
- Single-Board RIO
- ARM targets

System Flexibility and Price

Number of Systems Deployed

I/O
I/O
I/O
Custom I/O

LabVIEW

ni.com
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
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
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**
- Embedded Software Validation (HIL, MIL, SIL, RCP)

**Test Cells**
- Model-based test cells, HIL with mechanical components
- Mechanical Testing (Durability, Dyno, Environmental ...)

ni.com
Evolution of HIL Simulators
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

Simulink® is a registered trademark of The MathWorks, Inc. All other trademarks are the property of their respective owners.
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

- 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
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
ESO - ELT – Primary Mirror (M1) Control

- 984 Mirrors
- 3,000 Actuators
- 6,000 Sensors
- 3k x 6k Matrix
- 1 Millisecond
NI cRIO Node for Local Sensor / Actuator I/O
• 1 cRIO Node per Mirror

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

Supervisory Network
• 6 Distributed Mirror Controllers per Supervisor

Supervisor
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 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

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

\[ R \frac{\partial}{\partial R} \left( \frac{1}{R} \frac{\partial \psi}{\partial R} \right) + \left( \frac{\partial^2 \psi}{\partial Z^2} \right) = -\mu_0 R j_{\phi} \]

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
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

[Diagram of motor simulation]

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

NI CompactRio

NI LabVIEW Real-Time
- Traction Control
- Data Logging
- Driver Interface

NI LabVIEW FPGA
- Thermal Management
- Battery Management
- Safety Control
- Regenerative Braking
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)

\[
\begin{align*}
V_1(0) & \quad K_1 \\
K_2 & \quad V_2(0)
\end{align*}
\]

\[
Q_1 = K_1 \sqrt{DP_1};
\]

\[
Q_2 = K_2 \sqrt{DP_2};
\]
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”

CERN Large Hadron Collider
“the most powerful instrument on earth”

ni.com