Step-by-Step Data Acquisition for Test, Control, and Design
In This Seminar, You Will

• Build a measurement system with new NI data acquisition (DAQ) tools
  – Learn the parts of a typical DAQ system and their functions
  – Quickly set up and configure your DAQ system
  – Efficiently develop the application software for your DAQ system
  – Understand each measurement type: AI, AO, DIO, CTR

• Learn about real-world applications for DAQ
• Discover why NI data acquisition technologies are essential for reducing your total development time and cost
Profile

- *Leaders in Computer-Based Measurement and Automation*
- Long-term Track Record of Growth and Profitability
- Record number of new products released in 2004
- $514M Revenue in 2004
- $137M Revenue in Q4 2004
- 3,465 employees; operations in 40+ countries
- *Fortune’s 100 Best Companies to Work For Sixth Consecutive Year*
Diversity of Customers

More than 25,000 companies
Greater than 90% of Fortune 500 manufacturing companies
What is Virtual Instrumentation?

Traditional Vendor-Defined Instruments

Customer-Defined PC-Based Measurement and Automation Solutions

- Processor
- Display
- RAM
- Power Supply
- ROM
- Hard Disk
optional slide - if customers already familiar with NI, you can skip

Kristi Fairchild, 9/16/2004
What is Virtual Instrumentation? (continued)

Measurement Services & Application Software

Modular Hardware

Sensors or Unit Under Test (UUT)
optional slide - if customers already familiar with NI, you can skip
Kristi Fairchild, 9/16/2004
Virtual Instrumentation Applications

- **Test**
  - Physical/environmental measurements
  - Prototype validation
  - Manufacturing test
  - And more...

- **Control**
  - Industrial monitoring and control
  - Motion control
  - And more...

- **Design**
  - Simulation and prototyping
  - Design characterization
  - And more...
Developing a DAQ System – Four Steps

Source: 2004 National Instruments Survey of DAQ Customers and Prospects, n = 377
System Specification

System specification accounts for 7% of the total cost of data acquisition*

- Choose the right hardware and software
- Helpful resources

*Source: 2004 National Instruments Survey of DAQ Customers and Prospects, n = 377
What is a DAQ System?

Input Signals

Application Software (LabVIEW)

Output Signals

Measurement Services Software (NI-DAQmx)

Signal Conditioning

A/D
D/A
DIO
TIO

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DAQ Hardware Options

- Ethernet, Serial, or Wireless

- PXI
- Portable/Handheld

- Distributed

- Desktop
optional: slides in appendix with more information on comparing the hardware platforms
M Series – Next Generation Data Acquisition

• More Performance
  – Up to 18-bit resolution
  – Up to 1.25 MS/s sampling rates
  – NI-MCal: 5x accuracy improvement

• More I/O
  – Up to four analog outputs
  – Up to 48 digital I/O

• More Value
  – Lower prices
Signal Conditioning Hardware Options

Modular Signal Conditioning
- SCC
- SCXI

FieldPoint

Integrated Signal Conditioning
- PXI Instruments
- SC Series
- USB-9200 Series
DAQ Software Options

Test and Data Management Software
NI TestStand, DIAdem

Interactive Tools
SignalExpress
VI Logger

Application Development Software
LabVIEW
Graphical Development

LabWindows/CVI
ANSI C Development

Measurement Studio
Visual Studio Components

Measurement and Control Services:
NI-DAQmx or NI-DAQmx Base

Data Acquisition Hardware

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Basic Data Acquisition Driver

Typical Driver Software

Application Software

Driver Engine

Hardware
Measurement Services – NI-DAQmx

• Streamlined API
  – Polymorphic functions
  – Automatic code generation

• Improved Driver Architecture
  – Multithreaded measurements
  – Instant calibration
  – 20x faster for single-point operations
  – Code generation

NI-DAQmx Measurement & Control Services
LabVIEW Graphical Development Environment

- Compiled graphical development environment
- Development time reduction of four to ten times
- Tools to acquire, analyze, and present your data

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Helpful Resources for System Specification

• NI Field Engineers
  – Local to your area
  – Available to consult on your application, recommend products, etc.

• Online product advisors
  – Available for many types of products on ni.com/advisor
Today’s Demo System

- SCC Signal Conditioning Carrier and Modules
- NI-DAQmx and LabVIEW Software
- PCMCIA DAQCard
- Sensors
- Shielded Cable

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System Setup and Configuration

System setup accounts for 23% of the total cost of data acquisition*

- USB DAQ
- Sensors Plug&Play
- NI-DAQmx
  - Measurement & Automation Explorer (MAX) configuration utility

*Source: 2004 National Instruments Survey of DAQ Customers and Prospects, n = 377
Plug&Play DAQ Systems

• **USB DAQ**
  – Plug-and-play installation
  – Automatic driver association
  – No rebooting computer
  – Ready-to-run data logger included with some devices

• **Sensors Plug&Play**
  – Based on IEEE 1451.4
  – Confirm sensor connection
  – Eliminate paper data sheets
  – Remove data entry errors

• **Faster setup**
  – Decrease setup steps by up to 50%

[Image of Plug&Play DAQ Systems with components labeled and a diagram showing connection to LabVIEW via USB.]
Measurement and Automation Explorer (MAX)

- Task and channel creation
- Built-in test panel windows
- Device configuration and connection management
- Signal connection diagrams

ni.com
To Configure a DAQ System

• Install hardware
• Test it to make sure it works
• Configure signal conditioning
• Test to make sure signals are connected properly
Exercise 1 – Configuring an SCC DAQ System in MAX
need to add B & C portions to this exercise that show calibration, import/export wizard
Developing a DAQ System

Software development accounts for 30% of the total cost of data acquisition*

- AI/AO/DIO/CTR/Triggering/Synchronization
- NI-DAQmx Measurement Services software
- LabVIEW development environment

* Source: 2004 National Instruments Survey of DAQ Customers and Prospects, n = 377
Software Development Tools

• Configuration-based tools
  – SignalExpress (Test, Design)
  – VI Logger (Test)

• Programming tools (Test, Control, Design)
  – LabVIEW
  – LabWindows/CVI
  – Measurement Studio for Visual Studio.NET
Analog Input
Measuring Analog Input Signals

Important Factors to Consider

- Architecture – multiplexed versus simultaneous sampling
- Sampling rate
- Accuracy
  - Resolution
  - Absolute accuracy
  - Range and amplification
  - Noise and filtering
- Sensors and high voltage measurements
Analog Input – Architectures

Multiplexed

Channel 0
MUX
AMP
ADC

Channel 1

Simultaneous sampling

Channel 0
AMP
ADC

Channel 1
AMP
ADC

Channel 0
Channel 1
Analog Input – Sampling Rates

• Undersampling may result in the misrepresentation of the measured signal (aliasing).
• After a signal is aliased, it is impossible to reconstruct the original signal.
• For accurate frequency representation:
  – Sample at least 2x the highest frequency signal being measured.
• For accurate shape representation
  – Sample 5–10x the highest frequency signal being measured.
Analog Input – Resolution

• Number of bits analog-to-digital converter (ADC) uses to represent a signal
• Higher resolution – Detect smaller voltage changes
Accuracy versus Resolution

• Resolution
  – A property of the ADC

• Accuracy
  – A specification of the entire DAQ device or system
  – Includes many components and factors
    • ADC nonlinearities
    • Temperature
    • System noise
    • Amplifier gain and offset errors

• Higher resolution does not always equal more accurate!
  – Look for Absolute Accuracy specification
Analog Input – Range and Amplification

10 mV signal → ADC

Resolution: 16-bit
Range: ±10 V

32 levels of resolution

WITHOUT AMPLIFICATION
Analog Input – Range and Amplification

65,536 levels of resolution

10 mV signal

AMP
X100

ADC

Resolution: 16-bit
Range: ± 10 V

WITH AMPLIFICATION

** Amplification optimizes resolution over the range of measurement **
Analog Input – NI-PGIA 2 Custom ASIC

• PGIA = Programmable Gain Instrumentation Amplifier
• Fast settling times
• Optimized architectures for M Series families
  – Low cost
  – Fast settling
  – Low noise floor
• NI-DAQmx calculates gain automatically
Analog Input – Noise and Filtering

- Removes noise
- Blocks unwanted frequencies
- Prevents aliasing
High voltage signals and most sensors require signal conditioning to properly read the signal.

**Sensors/Signals**
- Thermocouples
- RTDs
- Strain Gauges
- Common Mode or High Voltages

**Signal Conditioning**
- Amplification, Linearization, and Cold-Junction Compensation, Filtering
- Current Excitation, Linearization, Filtering
- Voltage Excitation, Bridge Configuration, Linearization, Filtering
- Isolation

**DAQ Device**
Analog Input with M Series and LabVIEW

• Flexible programming options:
  – DAQ Assistant
  – Automatic code generation
  – API
    • Software timed
    • Hardware timed

• M Series analog input
  – Up to 18 bits of resolution
  – Up to 1.25 MS/s sampling rates
  – Correlated I/O
  – Optimized NI-PGIA 2 amplifiers
  – NI-MCal – Self-calibration at all input ranges
Exercise 2 – Measuring Temperature in LabVIEW

Method: DAQ Assistant
Analog Input – Application Example

• A Functional Test Bench for Power Tools
  - **Goal** – A single test bench for performing functional tests on commercial power tools
  - **How AI was used** – To acquire temperature, speed, and torque data from the various sensors attached to the device
  - **Results**
    • Better test accuracy than the previous manual methods
    • Simplified tracking
    • Faster rate of testing
    • 1/3 cost of a ready-made tool tester

Captronic Systems
Analog Output
Analog Output – Considerations

- Architecture
- Accuracy
  - Resolution
  - Absolute Accuracy
- Range
  - Adjustable versus Fixed

- Waveform Frequency
  - Update Rate
  - Settling Time
  - Number of Cycles in the Buffer
Analog Output with M Series and LabVIEW

- Same three methods as AI
  - DAQ Assistant
  - Code Generation
  - NI-DAQmx API
- Multiple AO operations can occur in parallel
- M Series analog output
  - Up to four 16-bit AO channels
  - Up to 2.8 MS/s output
  - Programmable AO ranges
  - Programmable DC offsets
Exercise 3 – Generating an Analog Output Waveform

Method: DAQ Assistant
Analog Output – Application Example

Stabilize a Fabry-Perot Interferometer

- **Goal** – Stabilize, maintain, and monitor the alignment of parallel mirrors in a Fabry-Perot interferometer with minimal user input

- **How AO was used** – To control the voltages applied to the three piezoelectric actuators, which controlled the mirror alignment

- **Results**
  - Simplified a previously tedious, manual task
  - Maintained alignment over a long period of time
  - More accurate data collection

NASA Glenn Research Center
Digital I/O
Digital I/O – Terminology

• General Terminology
  – Bit – The smallest unit of data. Each bit is either a 1 or a 0.
  – Line – One individual signal in a port. *Bit* refers to the data transferred. *Line* refers to the hardware.
  – Port – A collection of digital lines.

• M Series digital I/O
  – 10 MHz digital pattern I/O
  – Synchronization with AI and AO
  – Up to 48 digital I/O lines
NI-DAQmx Programming in LabVIEW

NI-DAQmx Task and Channel Constants

DAQ Assistant

Core Polymorphic VIs

Property Nodes

Advanced Utility Functions

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NI-DAQmx Programming in LabVIEW (continued)

Polymorphic VIs – A single Read VI is used for single or multiple channel analog or digital measurements.
Exercise 4 – Controlling Lights and Switches

**Method:** DAQ Assistant Code Generation
Digital I/O – Application Example

Radiation Measurement System for Cellular Phones

- **Goal** – Produce high quantity cellular phones with minimum staff by automating the radiation test process
- **How DIO was used** – To control seven-segment displays that identified error codes
- **Results**
  - Saved $900,000 per year
  - 100% increase in reliability

Samsung Electronics
Counter/Timers
Counter/Timers – Parts and Functions

- Two basic functions
  - To “count” based on the comparison of input signals (Gate, Source…)
  - To generate pulses based upon inputs and register value
Counter/Timers – Applications

- **Edge Counting**
  - Simple Edge Counting
  - Time Measurement
- **Pulse Generation**
  - Single Pulse Generation
  - Pulse Train Generation
- **Pulse Measurement**
  - Period Measurement
  - Pulse Width Measurement
- **Frequency Measurement**
- **Position Measurement**
- **Quadrature Encoder Measurement**
Counter/Timers with M Series and LabVIEW

• NI-DAQmx makes counters simple
  – Terminology “morphs” depending on application
  – NI-DAQmx will automatically connect specified input terminal to appropriate source or gate

• M Series counters (NI-STC 2 ASIC)
  – 32-bit counters, 80 MHz timebase
  – Quadrature encoder support
  – Debounce filtering
Exercise 5 – Counting Rising Edges with a Counter/Timer

Method: NI-DAQmx API
Counter/Timers – Application Example

Developing a Real-Time Functional Electrical Stimulation System

- **Goal** – Develop a functional electrical stimulation (FES) system that delivers stimulation patterns, acquires and stores data, monitors muscle responses, and modifies the stimulation patterns in real time to reflect physiological alterations.

- **How counters were used** – To drive a muscle stimulator and deliver the stimulation patterns.

- **Results**
  - Increased flexibility over previous methods
  - Met all originally set requirements

University of Delaware
Multiple Concurrent Operations
Multiple Operations – Single-Threaded

• Legacy NI-DAQ 6.9.x DAQ driver
  – Single-threaded driver
    • Parallel operations sometimes exhibit *blocking* (i.e., AI and AO)
    • Workaround requires extra programming with occurrences

• E Series
  – One to three DMA channels on E Series devices
    • Dedicated data highways for up to three operations
Multiple Operations – Multithreading and DMA

• NI-DAQmx
  – Multi-threaded driver
    • No blocking
    • No extra programming

• M Series
  – Six DMA channels on all devices
    • Dedicated data highways for all six operations
    • Greater total throughput
Demo 1 – Multithreading and DMA

With a Multithreaded DAQ Driver

Digital Loop: 1156
Analog Loop: 20
Digital Output: 0
Triggering and Synchronization
Triggering – Analog Triggering

Acquired Signal

Input Signal

Trigger Signal

Trigger Threshold

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NATIONAL INSTRUMENTS
Triggering – Digital

Acquired Signal

Input Signal

Trigger Signal
What Is Synchronization?

• Intra-board
  – Synchronization among multiple operations on the same device

• Inter-board
  – Synchronization among multiple operations on multiple devices

• Types
  – Shared trigger
  – Shared clock
  – Shared clock and trigger
Triggering and Synchronization with LabVIEW and M Series

- Methods of synchronization
  - External clock (shared hardware clock)
  - Real-Time System Integration (RTSI) bus

- NI-DAQmx
  - Automatic signal routing

- M Series
  - Correlated I/O
  - Generation and routing of RTSI signals for multi-device synchronization
  - Generation and routing of internal and external timing signals
  - PLL for clock synchronization
  - Trigger source options
    - Digital – Any PFI, RTSI, or PXI_STAR signals
    - Analog – APFI <0..1> or analog input channel
Synchronization – Application Example

- **Low Cost Integrated Road Simulator**
  - **Goal** – Develop a road simulator and virtual road simulator for the design and durability testing of Honda motorcycles
  - **How synchronization was used** – To provide synchronous operation of activation and measurement of achieved responses
  - **Results**
    - Lower cost (1/10 cost of purchasing turnkey system)
    - Shorter development time
    - Less need for expensive pre-production vehicles

Honda R&D Co., Ltd.
DAQ in Any Language

- Consistent DAQmx API across all languages
- Leverage the DAQ Assistant
- Generate code in LabVIEW, C, C++, VB, VB .NET, and C#

Measurement Studio

- Native .NET DAQ assemblies for Visual Studio .NET
- ActiveX DAQ controls for Visual Studio 6.0

LabWindows/CVI for ANSI C

- A complete ANSI C development environment for T&M
- ANSI C DAQ API

ni.com
DAQ with NI SignalExpress

- 100% interactive measurements
- Choose from 75 built-in acquisition and analysis functions
- Correlate SPICE simulations with real-world measurements
- Convert SignalExpress measurements to LabVIEW VIs

ni.com
Demo 2 – DAQ in Other ADEs
Software Development Summary

- NI-DAQmx Measurement Services Software
- LabVIEW
- Other software options:
  - VI Logger
  - SignalExpress
  - Measurement Studio
  - LabWindows/CVI
Developing a DAQ System

System validation and calibration accounts for 4% of the total cost of data acquisition

- NI-MCal
- Self calibration in MAX

Source: 2004 National Instruments Survey of DAQ Customers and Prospects, n = 377
### M Series Calibration – NI-MCal

<table>
<thead>
<tr>
<th>Feature</th>
<th>Benefit</th>
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<tbody>
<tr>
<td>Polynomial fit</td>
<td>Higher accuracy</td>
</tr>
<tr>
<td>Self-calibration at all ranges</td>
<td>Higher accuracy</td>
</tr>
<tr>
<td>Ultra-stable precision voltage reference</td>
<td>Two year calibration interval</td>
</tr>
<tr>
<td>Fast self-calibration</td>
<td>Four times faster than E Series</td>
</tr>
</tbody>
</table>

Analog inputs are 5x more accurate
NI-MCal Improves Accuracy by 5x

2-point calibration measures at 0V (ground) and 5 V (precision source) and applies linear correction to all measurements.

NI-MCal generates a 3rd order polynomial correction from multiple calibration points.

All analog-to-digital converters are nonlinear. ADCs on M Series devices exhibit 3rd order response.
A recent study of data acquisition users showed:

**On average, nearly 2/3 of total application cost is development time cost**

Source: 2004 National Instruments Survey of DAQ Customers and Prospects, n =377
Reduce Development Time and Total Application Costs with NI Data Acquisition Technologies

- **NI-DAQmx Measurement Services Software**
  - Fast, easy configuration
  - Faster programming with DAQ Assistant and auto-code generation
  - Faster, more accurate self-calibration with NI-MCal

- **DAQ Hardware**
  - M Series – Better performance, more value
  - USB – Fast setup and configuration
  - Sensors Plug&Play – Faster setup and programming

- **LabVIEW Development System**
  - Flexible development environment
  - Tight hardware integration through NI-DAQmx
Appendix

• Related products
• Services and support
• Detailed hardware platform comparisons
• Linux and DAQmx Base details
• Detailed application examples
Related Products – Other Multifunction DAQ

• S Series multifunction DAQ
  – Simultaneous sampling
  – Dedicated A/D converter per channel
  – Up to 16-bit resolution
  – Up to 10 MS/s

• Portable multifunction DAQ
  – For USB, PCMCIA, and FireWire
  – Up to 24-bit resolution
  – Up to 1.25 MS/s
NEW NI CompactFlash DAQ

• NI CF-6004
  – Four 14-bit AI channels
  – Sampling rate
    • Up to 200 kS/s single channel
    • Up to 100 kS/s multi-channel
  – Four DIO lines
• Programmable with LabVIEW PDA for PocketPC
• Applications
  – Biomedical/wearable computing
  – Automotive service
  – Remote monitoring/diagnostics
Related Products – Analog Output Devices

• **Waveform Output**
  – Up to 16-bit and 1 MS/s
  – Up to 32 channels per device
  – Simultaneous updates
  – External clocking and triggering
  – RTSI for multi-device synchronization

• **Software-Timed Output**
  – Voltage and current outputs
  – 16-bit output resolution
  – User-defined power-up states

• Available in PXI, PCI, and PCMCIA
Related Products – Digital and Timing I/O

• Static (software-timed) DIO
• High Speed DIO
  – Dedicated digital devices
  – Up to 100 MHz clock rates
  – Up to 64 Mbits/ch onboard memory
  – Programmable voltage levels (–2.0 to 5.5 V)
• Industrial
  – Up to 60 V ranges
  – High Reliability Industrial Feature Set
    • Programmable Power-Up States
    • Watchdogs
    • Change Detection
    • Programmable Input Filters
    • Built-in bank or Ch-Ch isolation
• NI-DAQmx Software Technology
DAQ with Extended Functionality

• SC Series
  – Integrated signal conditioning for PXI

• Compact FieldPoint
  – Distributable, networked

• CompactRIO
  – Rugged, embedded DAQ and control
Global Service and Support

• Award-Winning Support
  – 3,000+ example programs
  – 100+ application notes
  – 7,000+ knowledge bases

• Field Engineers
  – More than 200 engineers worldwide
  – Ready to provide on-site assistance
Global Service and Support

- Factory installation services
- Onsite courses for software and hardware
- Technical workshops with content customized for your company/industry
- Online tutorials for NI products and technologies
## Hardware Platforms – Detailed Comparison

<table>
<thead>
<tr>
<th></th>
<th>Distributed (Ethernet)</th>
<th>Desktop (PCI)</th>
<th>PXI</th>
<th>Portable/Handheld</th>
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</thead>
<tbody>
<tr>
<td><strong>Performance</strong></td>
<td>Slow (&lt;10 Hz)</td>
<td>Medium-Fast (&lt;10 MHz)</td>
<td>Medium-Fast (&lt;2.7 GHz)</td>
<td>Medium (&lt;1.25 MHz)</td>
</tr>
<tr>
<td><strong>Capacity (I/O Count)</strong></td>
<td>Medium</td>
<td>Medium-High</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Rugged Packaging</strong></td>
<td>Best</td>
<td>Good</td>
<td>Better</td>
<td>Good</td>
</tr>
<tr>
<td><strong>Bus</strong></td>
<td>Ethernet</td>
<td>PCI</td>
<td>PXI/CompactPCI</td>
<td>USB, FireWire, PCMCIA, CompactFlash</td>
</tr>
<tr>
<td><strong>Advanced Features</strong></td>
<td>Real-time, embedded data logging</td>
<td>Real-time</td>
<td>Real-time, advanced synchronization</td>
<td>Portability, wireless communication</td>
</tr>
</tbody>
</table>
Linux and NI-DAQmx Base Details

• NI-DAQmx Base – Driver software for NI hardware and
  – Linux (E Series, some USB DAQ devices)
  – PocketPC (PCMCIA E Series, CompactFlash DAQ)
  – Mac OS X (E Series, some USB DAQ devices)
  – Windows (some USB DAQ devices)

• Subset of NI-DAQmx functionality
• Free download at ni.com/downloads
• Measurement Hardware DDK also available for RLP
Detailed Application Examples