Developing Measurement and Analysis System using MATLAB

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Senior Application Engineer
MathWorks Korea
Agenda

- Great Demo : Battery test demo
- Overview of data acquisition capabilities from MATLAB
- Simple examples
- Acquiring data from stand alone application
  - MATLAB Compiler
- Summary
- Q&A
Realistic Example of T&M System.

Battery Testing Demo
Control Algorithm Development

- What do I do first?
  - Understand the plant behavior.

- How can I do that?
  - Build a plant model
  - Use the plant model to develop controller
Battery Equivalent Circuit

\[ R_x = f(SOC, \text{Current}, \text{Voltage}, \text{Temperature}) \]
Simulink Model

What did I just modeled?

OR

OR

OR
Model Correlation

- Every model needs to be correlated against real data.

\[ R_x = f(\text{SOC}, \text{Current}, \text{Voltage}, \text{Temperature}) \]
What is Model Correlation?

- A form of Data Analysis
  - Take raw data
  - Transform it into applicable form
  - Apply it to make engineering decision
Data Analysis Tasks

Access
- Files
- Software
- Code & Applications
- Hardware

Explore & Discover
- Data Analysis & Modeling
- Algorithm Development
- Application Development

Share
- Reporting and Documentation
- Outputs for Design
- Deployment

Automate
Data Analysis Tasks

- **Access**
  - Bring data into MATLAB
    - Test and Measurement Toolbox
    - Vehicle Network Toolbox
  - Ensure data integrity *during* data collection
    - Voltage threshold
    - CAN dropout
Data Analysis Tasks

Access
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- Hardware
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Explore & Discover
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- Algorithm Development
- Application Development

MathWorks
Data Analysis Tasks

- Explorer and Discover

  Data
  - Managing heterogeneous data
  - Visualizing

  Quality
  - Combining different sampling rates
  - Handling missing data
  - Identifying bad data (outliers)
Demo: Pre-Processing of Test Data

- **Goal:**
  - Prepare data for further analysis

- **Approach:**
  - Load data from files
  - Combine different sampling rates to unified time scale
  - Handle missing data
  - Identify outliers
Demo: Pre-Processing of Test Data

- **Goal:**
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Joins for Datasets

- Merge datasets together

- Popular Joins:
  - Inner
  - Full Outer
  - Left Outer
  - Right Outer
### Full Outer Join

**First Data Set**

<table>
<thead>
<tr>
<th>Key</th>
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**Second Data Set**

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**Joined Data Set**

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Inner Join

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Left Outer Join

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Demo: Pre-Processing of Test Data

- **Goal:**
  - Prepare data for further analysis

- **Approach:**
  - Load data from files
  - Combine different sampling rates to unified time scale
  - Handle missing data
  - Identify outliers
Techniques to Handle Missing Data

- **List-wise deletion**
  - Unbiased estimates (assuming that the data is MCAR)
  - Reduces sample size
  - Loss of power

- **Implementation options**
  - Listwise deletion is built in to many MATLAB functions
  - Manual filtering
Techniques to Handle Missing Data

- **Substitution** - Replace missing data points with a reasonable approximation

  - Easy to model
  - Too important to exclude
Techniques to handle missing data

- **Substitution:** Replace the missing data point with something reasonable

- Enables other types of analysis

- Error estimates will be biased
Techniques to handle missing data

- Substitution: Replace the missing data point with something reasonable
Techniques to handle missing data

- Substitution: Replace the missing data point with something reasonable
Techniques to handle missing data

- Substitution: Replace the missing data point with something reasonable

Median Substitution
Techniques to handle missing data

- **Substitution**: Replace the missing data point with something reasonable

![Graph showing linear interpolation](Image)
Techniques to handle missing data

- Substitution: Replace the missing data point with something reasonable

Regression Substitution (Linear)
Techniques to handle missing data

- **Substitution:** Replace the missing data point with something reasonable

More complicated model:
- Nonlinear regression
- Smoothing spline
- Localized regression
- …
Techniques to handle missing data

- Substitution: Replace the missing data point with something reasonable

[Graph showing different methods such as Mean Substitution, Median Substitution, Linear Interpolation, and Regression Substitution (Linear and Nonlinear).]
Demo: Pre-Processing of Test Data

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Demo: Pre-Processing of Test Data

Summary

- Managed data with dataset array
- Merged dataset arrays with join
- Resampled data with fit objects and filled in missing values
- Identified outliers using statistical analysis
Technical Computing Workflow

Access
- Files
- Software (languages/applications)
  - Java
  - Perl
  - C/C++
  - Fortran
  - ASCII
- Hardware

Explore & Discover
- Data Analysis & Modeling
- Algorithm Development
- Application Development

Automate

Share
- Reporting and Documentation
  - Word
  - Excel
  - Access
  - Adobe
- Outputs for Design
- Deployment
  - .NET
  - .exe
  - MATLAB
  - Java
  - Excel Add-in
  - WWW
MATLAB Connects to Your Hardware

**Data Acquisition Toolbox**
Plug in data acquisition boards and modules

**Instrument Control Toolbox**
Instruments and RS-232 devices

**Image Acquisition Toolbox™**
Image capture devices

**Vehicle Network Toolbox**
CAN bus interface devices

**MATLAB**
Interfaces for communicating with everything
Data Acquisition Toolbox™: Supported Hardware

- Agilent Technologies
- Keithley
  - ISA, PCI, PCMCIA
- Measurement Computing Corporation
  - USB, PC/104, ISA, PCMCIA, Parallel port
- National Instruments
  - Hardware supported by NI-DAQ, NI-DAQmx drivers over AT, PCI, PCI Express, FireWire, PXI, SCXI, PCMCIA, parallel port, USB, CompactDAQ
- Any Windows compatible sound cards (AI, AO)
- IOtech
  - DaqBoard, DaqBook, DaqLab, DaqScan, Personal Daq/3000, and WaveBook Series
- Data Translation
  - All USB and PCI boards
- CONTEC
  - Various boards through CONTEC ML-DAQ adaptor
- Advantech

For a complete list, visit [www.mathworks.com/products/daq/supportedio.html](http://www.mathworks.com/products/daq/supportedio.html)
Demo: Acquiring and analyzing data from sound cards

- Windows sound card
- Frequency Analysis
- Live Data
- Graphical User Interface
Analyzing sensor data from MATLAB

Physical Quantity → Sensor / Transducer → Voltage → Hardware

Measurement Types
- Temperature
- Pressure
- Flow
- Acceleration
- Rotation
- Strain
- ...

Computer
Data Acquisition Toolbox

- What kind of hardware can I use?
  - Supports for a variety of data acquisition boards and USB modules

- Key Features
  - Support for analog input, analog output, counters, timers, and digital I/O
  - Direct access to voltage, current, IEPE accelerometer, and thermocouple measurements
  - Live acquisition of measured data directly into MATLAB or Simulink
  - Hardware and software triggers for control of data acquisition
  - Device-independent software interface
What’s new in recent releases of Data Acquisition Toolbox?

- Two interfaces to connect to DAQ hardware
  - Legacy interface
  - Session-based interface (NI-only)
- Support the following on NI hardware
  - IEPE accelerometer measurements
  - Bridge-based sensors measurements
  - Thermocouple and RTD measurements
  - Counter/Timer operations
  - Analog Input, Analog Output, Digital I/O
  - Synchronization and Triggering functions
## Session Interface vs. Legacy Interface

<table>
<thead>
<tr>
<th>Feature</th>
<th>Legacy</th>
<th>Session</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multi-vendor support</td>
<td>yes</td>
<td>No, NI only</td>
</tr>
<tr>
<td>Sound card support</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>32-bit ML on 32 or 64-bit Windows OS</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td><strong>64-bit ML</strong></td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Analog Input</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Analog Output</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Digital I/O</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td><strong>Counter/Timer</strong></td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Voltage Measurements</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Current</td>
<td>No*</td>
<td>yes</td>
</tr>
<tr>
<td>Thermocouple, RTD</td>
<td>No*</td>
<td>yes</td>
</tr>
<tr>
<td><strong>IEPE accelerometer, Bridge</strong></td>
<td>No*</td>
<td>yes</td>
</tr>
<tr>
<td>Advanced Synchronization capabilities (applies to NI)</td>
<td>yes</td>
<td>yes</td>
</tr>
</tbody>
</table>

**See [supported hardware page](#) for available interfaces for a specific NI device**
# Key Capabilities & Benefits (DAT)

<table>
<thead>
<tr>
<th>Capabilities</th>
<th>Benefits</th>
</tr>
</thead>
</table>
| Connect to a wide variety of DAQ hardware using a common set of commands | **Freedom to choose the hardware that is right for the task**  
Easier to maintain code and leverage previously written code for new projects with different hardware |
| Access to hardware capable of specialized measurements such as IEPE accelerometer, thermocouple and Bridge | **Simplifies measurement test setup since the signal conditioning is in the hardware**  
Connect the sensor and acquire the data in the desired engineering units (g, degrees K etc.) without conversions or lookup tables |
| Access to counter/timer measurements | **Full access to the capability of the DAQ card**  
Simplifies applications involving counting, pulse width and frequency measurements |
| Advanced Synchronization | **Synchronize data collection from multiple devices**  
Auto synchronization capabilities, external event based triggering |
| Enables live analysis of acquired data | **Simplified background data acquisition**  
Analyze data as you collect it. Reduce collection of bad data |
Instrument Control Toolbox

- What are the key features of Instrument Control Toolbox?
  - IVI, VXIplug&play, and native MATLAB instrument driver support
  - GPIB and VISA (GPIB, GPIB-VXI, VXI, USB, TCP/IP, and serial) support
  - TCP/IP, UDP, and Bluetooth serial protocol support
  - Interactive tool for identifying, configuring, and communicating with instruments
  - Simulink® blocks for sending and receiving live data between instruments and Simulink models
  - Functions for reading and writing binary and ASCII data to and from instruments
  - Synchronous and asynchronous (blocking and nonblocking) read-and-write operations
Instrument Control Toolbox: Supported Hardware

- Instruments from Agilent, Anritsu, LeCroy, Rohde & Schwarz, Tabor, Tektronix, and others

- Instruments and devices supporting common communication protocols (GPIB, VISA, TCP/IP, UDP, and serial, Bluetooth)

- Serial devices – Any device with a RS-232, RS-422, or RS-485 interface (EEGs, gas chronometers, mass spectrometers, etc.)

- Instruments using industry-standard instrument drivers (IVI, VXIplug&play, LXI)

For a complete list, visit http://www.mathworks.com/products/instrument/hardware/index.html
Acquiring Data Using the Test and Measurement Tool

Features:
- Export directly to Figure Window
- Export to MATLAB workspace
Test and Measurement Tool Features

Features:
- View driver properties
- View driver functions
- Create device objects
- Create interface objects
- View connected hardware
Session Log

Features:
- Automatically creates MATLAB code from activity within the tool
- Comments the code
- Can be saved for use in application
What’s new in recent releases of Instrument Control Toolbox

- Bluetooth support
  - Serial Port Profile (SPP)
- I2C support
- Quick Control Instruments
  - Quick Control Oscilloscope
  - Quick Control Function Generator
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Control and acquire data from instruments using IVI, VXIplug&amp;play and MATLAB instrument drivers</td>
<td><strong>Verify designs and build test systems</strong>&lt;br&gt;Instrument Control Toolbox and MATLAB as a platform for design verification. Develop models in MATLAB or Simulink and test them with data generated or collected from test equipment. Verify that prototypes meets specs and build larger test systems.</td>
</tr>
<tr>
<td>Connect to instruments and devices over GPIB, TCP/IP, VISA, USB and Serial and Bluetooth and I2C</td>
<td><strong>Easily connect to hardware without leaving MATLAB</strong>&lt;br&gt;Analyzing data, visualizing data and developing custom measurements all in the single environment saves time.</td>
</tr>
<tr>
<td>Quick Control Instruments</td>
<td><strong>Connect to instruments without knowing SCPI or driver commands</strong>&lt;br&gt;Connect to oscilloscopes and function generators with only a few lines of MATLAB code</td>
</tr>
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<td>Connect to remote software applications using TCP/IP or UDP</td>
<td><strong>Enables analysis of data collected from a remote source</strong></td>
</tr>
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Summary

- Acquire Data from sensors and Instruments
  - Data Acquisition Toolbox
  - Instrument Control Toolbox
  - Image Acquisition Toolbox
  - Vehicle Network Toolbox

- Without leaving MATLAB you can acquire, analyze and visualize your data

- Acquiring and analyzing data from the same environment saves time and enables live analysis of data
Resources

- Data sheets, user stories, demos, technical literature, documentation
  - [www.mathworks.com/products](http://www.mathworks.com/products)
- View this and other archived webinars
  - [www.mathworks.com/products/daq](http://www.mathworks.com/products/daq)
- View more data acquisition demos
- View more instrument control demos
- View supported hardware
  - Data Acquisition Toolbox
  - Instrument Control Toolbox
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  - Vehicle Network Toolbox