Control System Design and Rapid Prototyping Using Simulink

Chirag Patel
Sr. Application Engineer – Modeling and Simulink
MathWorks India
Are you using different tools for design & real-time testing?
Do you make design changes during field & real-time testing?
Is your test data under utilized or not fully leveraged for design improvements?
Solution?
Integrated Design Workflow

Based on

Control Design Products and Simulink Real-Time
Agenda

Tuning Controller Parameters

- Classical control tuning techniques
- Optimization-based system response tuning

Real-Time Testing and Simulation

- Prepare models for real-time execution
- Connect models with hardware under test using flexible real-time testing hardware
- Tune parameters and log/monitor signals during real-time execution using Simulink Real-Time™ Explorer
- Automate real-time test routines using MATLAB® scripts
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Tuning Commonly used PID Controllers

Improved workflow for tuning PID controllers in Simulink
Redesigned PID Tuner

Improved workflow for tuning PID controllers in Simulink

- Several response plots can be displayed simultaneously
- Controller can be evaluated against several plant models
- Model can be relinearized at a visually selected simulation snapshot

Select a snapshot to relinearize at based on closed loop error signal
System Identification Integrated into PID Tuner in Simulink Control Design

Tune PID Controllers for Simulink models with discontinuities such as PWM and Stateflow logic

- Compute plant transfer function from simulation input-output data when exact linearization fails
- Inject a step or an impulse at the plant input
- Interactively or automatically fit the transfer function to simulation input-output data
Tuning Complex Fixed Structured Controllers
Control System Tuner App - Robust Control Toolbox

Tune fixed-structure controllers in Simulink

- Specify blocks to tune
- Add tuning goals
- Visualize tuning results
- Update tuned Simulink blocks from app
Tuning of Gain-Scheduled Controllers with *systune* and *looptune*

Automatic tuning of controller gains at all operating conditions to meet design requirements and create smooth gain surfaces

- New *gainsurf* command for parameterizing controller gains as functions of scheduling variables
- Software automatically tunes coefficients of that parameterization
SYSTUNE Inside

- Gain surface tuning leverages **SYSTUNE** technology

- No restriction on control structure, number of feedback loops, or compensator types
SYSTUNE Inside

- Variety of tuning goals available to express control objectives

Gain bounds
Loop shape
Stability Margins

Decay rate, damping, natural frequency
Stochastic disturbance attenuation
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Controller Tuning Using Optimization Based Techniques

- Tune model parameters using numerical optimization to meet desired system performance
- Handle plants with discontinuous events and nonlinearities
- Used by system and control engineers to optimize physical system, controller, and overall design
Family of Control Design Products

- Control System Toolbox
- Simulink Control Design
- System Identification Toolbox
- Robust Control Toolbox
- Simulink Design Optimization
- Model Predictive Control Toolbox
- Fuzzy Logic Toolbox
- Neural Network Toolbox
Control Design Is Done.

What’s Next?

Real-Time Simulation and Testing?
Agenda

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Real-Time Testing and Simulation

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Why do Model-Based Design Real-Time Simulation & Testing?

It enables you to:

- **Test, verify, and validate** your algorithmic and system designs earlier

- **Achieve determinism** through system modeling, automatic code generation and real-time software/hardware execution

- **Evaluate new ideas** using a flexible, scalable, production independent development platform

- **Minimize risk, reduce costs, shorten time-to-market**
Simulink Real-Time™ Enables Real-Time Simulation & Testing

Rapidly create real-time applications from Simulink models and run and test them with your hardware under test at normal operating frequencies, speeds, and timing.

“Using Model-Based Design with MATLAB and Simulink, we achieved multiple goals simultaneously. We developed a sophisticated controller for digital hydraulics that is more reliable, accurate, and efficient than previous systems, and we accelerated development, which gives us a competitive advantage.”

Kari Leminen, Metso
Real-Time Simulation & Testing Tasks:

**Rapid Controls Prototyping**

1. **Test Suite**
2. **Controller Model**
3. **I/O Output**
4. **I/O Input**
5. **Verification**

**System Model**

- **Physical Plant Hardware**
- **Wiring and Signal Conditioning**
- **Target Computer Hardware**

1-Click Code Generation and Download
Real-Time Simulation & Testing Tasks:

**Hardware-in-the-loop (HIL) Simulation**

1. **Controller Model**
2. **Plant Model**
3. **Verification**
4. **Code Generation and Download**

**Wiring and Signal Conditioning**

**Embedded Controller Hardware**

**Target Computer Hardware**
Additional Real-Time Simulation & Testing Tasks:

*Parametric Evaluation and Performance Assessment*

- System robustness
  - Monte Carlo analysis
  - Operational envelope testing

- Human factors
  - Human-in-the-loop simulation
  - Virtual reality simulators

- Calibration
  - Tune algorithmic coefficients
  - Optimize performance
What is Simulink Real-Time?

From desktop simulation to real-time

Creation of real-time applications from Simulink models and loading them onto dedicated target computer hardware in 3 automated steps:

1. Code Generation
2. Compile & Link
3. Download & Ready to Run
What is Simulink Real-Time?

Connect to your physical system

- Support for a broad range of I/O types and communication protocols
- Easy drag & drop and configuration within a Simulink model
What is Simulink Real-Time?

*Multiple systems and multiple uses*

**One license supports**

- Creation and simultaneous control of many systems
- Many real-time uses
  - Real-time simulation and testing
  - Data acquisition and instrumentation
  - Lab controllers
- Stand alone operation
What is Simulink Real-Time?

Extendable, integrated, and interactive

1. Live parameter tuning, signal monitoring, and execution control
2. Data logging for offline analysis in MATLAB
3. UI/HMI connectivity
4. Extensibility with other software tools (e.g. virtual reality)
Simulink Real-Time™
*Build, run and test real-time applications*

**What it is…**
Simulink Real-Time lets you create real-time applications from Simulink models and run them on dedicated target computer hardware connected to your physical system. It supports real-time simulation and testing, including rapid control prototyping, DSP and vision system prototyping, and hardware-in-the-loop (HIL) simulation.

**What is included…**
- Tools, UIs, functions, and blocks to control, monitor, and tune real-time applications
- Connectivity interfaces to external physical systems and external software
- A multicore/multitasking real-time kernel with microsecond granularity and concurrent execution support
- Ability to perform co-execution of applications running on a real-time target computer with FPGAs
- Integration with the whole MathWorks’ environment
What Hardware is used with Simulink Real-Time?

Real-time software environment + real-time target computer

Development Computer with MATLAB & Simulink & Simulink Real-Time

Target Computer Hardware from Speedgoat
Speedgoat Provides Real-Time Target Computers

*Made for use with Simulink Real-Time*

Speedgoat develops and sells Real-Time Machines consisting of

- An industrial PC (Real-time target machine)
- I/O modules
- Software drivers, cables and tools to connect with a prototype

Simulink Real-Time and Speedgoat target computer hardware are expressly designed to work together.

Real-time target machine

I/O modules installed in target machine

I/O Cable

Terminal board

Simulink drivers

Simulink test models
About Speedgoat

- Highly specialized developer of turnkey real-time target machines
- Incorporated in 2007 by former MathWorks employees
- Located in Bern, the Swiss capital
- Over 1,000 Real-time target machines sold to date, all for use with Simulink
- ~75% of all new Simulink Real-Time seats are accompanied by a Speedgoat system
Speedgoat Real-Time Target Machines
Assembled based on your technical requirements

- Form factors available for office, lab, field, and classroom use
- Optimized for highest real-time performance (Multicore CPUs and FPGAs)
- Fully tested and works out-of-the-box
- Flexible, expandable architecture supporting a wide range I/O connectivity

* Custom engineering and I/O module development available
## Fixed-Function I/O Modules

*Powerful “as is” functionality*

<table>
<thead>
<tr>
<th>IO Type</th>
<th>Functionality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analog</td>
<td>High-resolution, high-speed, simultaneous sampling, BNC and XLR panels, …</td>
</tr>
<tr>
<td>Digital</td>
<td>TTL/LVCMOS, RS422/RS485/LVDS, 06-48V, low/high side, opto-coupled, …</td>
</tr>
<tr>
<td>Serial</td>
<td>RS232, RS422, RS485, SDLC, HDLC</td>
</tr>
<tr>
<td>Ethernet-based</td>
<td>EtherCAT, EtherNet/IP, Modbus TCP, POWERLINK, real-time UDP, …</td>
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<tr>
<td>Video</td>
<td>CameraLink, USB WebCam</td>
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<tr>
<td>Audio/Speech</td>
<td>Audio/Speech optimized analog IO modules</td>
</tr>
<tr>
<td>Shared Memory</td>
<td>Reflective Memory for high speed data transfer in multi-processor systems</td>
</tr>
<tr>
<td>Various</td>
<td>LVDT/RVDT, Synchro/Resolver, reed relays, programmable resistors, external signal conditioning modules (current to voltage, voltage to current, temperature, …)</td>
</tr>
</tbody>
</table>

- Delivery includes I/O cables, terminal boards, test models, and Simulink driver blocks
- 3 years of warranty, and long-term availability (7+ years for most I/O modules)
Multi-Function I/O Modules

Reconfigurable to support your application

- Execute high-speed algorithms on an FPGA connected to a model running in real time with Simulink Real-Time.
- Automatically program the FPGA without needing to know HDL code
- Quick reconfiguration of FPGA I/O promotes a flexible real-time testing environment.
- Three different use cases supported
  - Pre-configured FPGA Code Module functionality
  - Execute Simulink Applications on FPGA using automatic HDL Code Generation
  - Write and implement your own HDL Code using Speedgoat FPGA Engineering Kits
Take Advantage of the Hardware

*To increase speed and handle application complexity*

Speed up real-time applications by partitioning the model for:

- Concurrent Execution across multiple cores and FPGAs in a single target computer
- Distributed Execution with multiple target computer hardware systems
Interacting with the Simulink Real-Time Application

*Monitoring, tuning, and control of real-time applications*

- Support multiple ways of working and interacting
  - Simulink Real-Time Explorer
  - Simulink External Mode
  - MATLAB command scripts
  - MATLAB UIs
  - Simulink Real-Time external APIs
  - 3rd party visualization tools

- Manage and control multiple target computers simultaneously
Control and Explore Your Real-Time Application

**Built-in control and monitoring User Interface**

**Simulink Real-Time Explorer**

- Control target computer specific properties
- Easy access to the model hierarchy
- Commit parameter updates individually or as groups
- Add scopes and data logging on the fly
- Graphical controls and displays to design and run instrument panels
Monitor and Tune Real-Time Application

Directly from Simulink using Simulink Coder’s External Mode

Direct interactive access from the Simulink model

- Apply parameter changes
- Monitor the impacts in scopes and displays
- Support for 3D and Stateflow animations
- Log test data
Access Real-Time Application from MATLAB

MATLAB scripts incorporate and automate testing with analysis

- Leverage entire MATLAB language to access and control all aspects of your real-time application
- Use interactively from the command line as well as from scripts
- Augment testing with MATLAB toolboxes and functions such as
  - Optimization Toolbox for tuning parameters
  - Signal Processing Toolbox for post-processing data
  - Report Generator for automation of tests and publishing results
Create UIs in MATLAB

Graphical front end for your MATLAB scripts and programs

- **Create a MATLAB UI Interactively**
  - Easily design your UI graphically in the GUIDE Layout Editor
  - Automatically generates MATLAB code to add your scripts to

- **Create a MATLAB UI Programmaticallly**
  - Allows more control and customization
  - Built-in functions and graphical controls
  - Add your own graphical controls with Java and ActiveX

- **Deploy as a MATLAB App**
Create UIs Independent of MATLAB

*Use built-in, flexible APIs*

**Simulink Real-Time External APIs**

- .NET, C, COM
- Can be used with leading UI design environments such as
  - Microsoft Visual Studio
  - Qt Creator
  - Altia
- Connect the target application with other external applications or UIs
Works With 3\textsuperscript{rd} Party Drag & Drop HMI Tools

*HMI tool to interface with real-time applications*

**Example:** VISUALCONNX

- Intuitive "drag and drop" multi-windowed UI
- Data aware controls
- Supports scripting for advanced functionality
- Supports both model testing and real-time testing
- MathWorks Connection Partner
Benefits of a Simulink Real-Time Solution

**Fully assembled solution**
- Focus on developing your next generation software and hardware designs instead of developing the tools & hardware infrastructure

**Shorten time-to-market**
- Benefit from a flexible and production independent platform which can be easily adapted to changing requirements
- Prove and improve your Simulink design with your hardware at the earliest possible stage and continuously try new ideas

**Reduce costs**
- Avoid otherwise costly design flaws by detecting errors at a stage where they are still cost effective to correct
- Simulate and automate test scenarios and hardware interactions which are otherwise complex, expensive, or dangerous to perform
Recorded Webinars & Examples

Watch a recorded webinar:

A Simulink Real-Time Testing Solution for Power Electronics & Motor Control

http://www.mathworks.com/company/events/webinars/wbnr68656.html

Prove Your Simulink Designs with Real-Time Hardware Testing

https://www.mathworks.com/company/events/webinars/wbnr73147.html

Explore example models:

Field-Oriented Control of a Permanent Magnet Synchronous Machine

This example shows the basic workflow and key APIs for generating C code from a motor control algorithm, and for verifying its compiled behavior and execution time.


Simulink Real-Time

Examples demonstrating features of Simulink Real-Time.
(real-time parameter tuning, signal monitoring, data logging, and more)

Summary
Integrated Workflow

Seamless transition from design to real-time testing
Early Verification

Discover hardware/software integration issues during lab testing
Leveraging Test Data

Improve your models and design from test data