Model-Based Design of a Quadcopter

Ryan Gordon
Model-Based Design Adoption Grid

- Virtual V&V
- System Validation
- Fully leveraged MBD
- Closed-Loop Simulation
- HW-in-the-Loop Simulation
- Simulation-based Development
- Graphical Specification
- Design Prototyping
- Graphical Programming

Simulation
Real-Time Test
Production
Model-Based Design Adoption Grid

Model
Graphical Specification
Simulation
Real-Time Test
Production

Req.
System
Algorithm
Model-Based Design Adoption Grid

Closed-Loop Simulation

Graphical Specification

Simulation  Real-Time Test  Production
Model-Based Design Adoption Grid

Virtual V&V

Closed-Loop Simulation

Graphical Specification

Simulation

Real-Time Test

Production

Controller

Plant

Machine Performance Requirements:

Lift System Response

Time to lift rated load
With the linkage being at the lower most position where the lift cylinder is at full stroke, with the bucket loaded with rated load (5000kg), when the loader operator issues a command to lift, the lift system should move through its complete range of motion (lift cylinder being at its maximum stroke at the end of the motion) in 6.5 seconds or less.

Response to step input from operator
With the linkage being at the lower most position where the lift cylinder is at minimum stroke with the bucket loaded with rated load (5000kg), when the loader operator issues a step
Model-Based Design Adoption Grid

- Virtual V&V
- System Validation
- Closed-Loop Simulation
- HW-in-the-Loop Simulation
- Graphical Specification
- Design Prototyping
Model-Based Design Adoption Grid

Virtual V&V
System Validation
Fully leveraged MBD
Closed-Loop Simulation
HW-in-the-Loop Simulation
Simulation- based Development
Graphical Specification
Design Prototyping
Graphical Programming

Simulation
Real-Time Test
Production
Model-Based Design Adoption Grid

- Virtual V&V
- System Validation
- Fully leveraged MBD
- Closed-Loop Simulation
- HW-in-the-Loop Simulation
- Simulation-based Development
- Graphical Specification
- Design Prototyping
- Graphical Programming

Simulation
Real-Time Test
Production
Model-Based Design Adoption Grid

1. Where are you?
2. Which path(s) do you want to take?

Virtual V&V
System Validation
Fully leveraged MBD

Closed-Loop Simulation
HW-in-the-Loop Simulation
Simulation-based Development

Design Prototyping
Graphical Programming

Simulation
Real-Time Test
Production

Your Organization ???

Your Organization ???
Demo Agenda

- Build Quadcopter Simulation with SimMechanics
- Build Control System with Simulink Control Design
- Deploy to Hardware with Embedded Coder and Custom Target
Demo Agenda

- Build Quadcopter Simulation with SimMechanics
- Build Control System with Simulink Control Design
- Deploy to Hardware with Embedded Coder and Custom Target
Introduction to Simulink®

- Block-diagram environment
- Model, simulate, and analyze multidomain systems
- Design, implement, and test:
  - Control systems
  - Signal processing systems
  - Communications systems
  - Other dynamic systems
- Platform for Model-Based Design
Introduction to SimMechanics

- Enables multibody simulation of 3D mechanical systems

- Construct model using bodies, joints, and forces
  - Model matches structure of system
  - No need to derive and program equations

- Primary uses
  - System-level analysis
  - Control development in Simulink
Equations of Motion

\[ \text{thetadotdot} = -\frac{g}{l} \sin(\text{theta}) \]
Demo Agenda

- Build Quadcopter Simulation with SimMechanics
- Build Control System with Simulink Control Design
- Deploy to Hardware with Embedded Coder and Custom Target
Introduction to Simulink Control Design

- Automatically tune gains of PID controllers
- Rapidly perform advanced linear analysis and control design for plants modeled in Simulink

\[ A \mathbf{x} + B \mathbf{u} = 0 \]
Demo Agenda

- Build Quadcopter Simulation with SimMechanics
- Build Control System with Simulink Control Design
- Deploy to Hardware with Embedded Coder and Custom Target
Intro to Automatic Code Generation

- ANSI-C Code generation for embedded microprocessors
  - MATLAB Coder
  - Simulink Coder
  - Embedded Coder

- HDL Code Generation for FPGAs and ASICs
  - HDL Coder
  - HDL Verifier

- PLC Code Generation
  - Simulink PLC Coder
Usage of Embedded Coder

- Generate C Code
- Merge with Existing Code-Base (manual integration)
- Shared Library / DLL (ie: integrating with another application)
- Target specific platform, stand-alone execution
Usage of Embedded Coder

Generate C Code

- Target specific platform, stand-alone execution
  - Custom-Target

- Merge with Existing Code-Base (manual integration)

- Shared Library / DLL
  (ie: integrating with another application)
What the user sees: Build-Tool Chain Interface

Custom Hardware

Custom Compiler/Toolchain
How we generated a full program executable

Sensor Drivers
(Rate Gyro, Accelerometer, Ultrasound height)

Controller Model w/Driver Blocks

Generated Algorithm Code

Actuator Drivers
(LEDS, Propellers)

Written manually by hand

Linux Operating System Scheduler

Tuning With External Mode

Used External Mode API from Embedded Coder
External Mode

a) Visualize signals/values of generated code in Simulink as executable is running

b) Change values of parameters in real-time. No re-compilation to change a single gain value

Out-of-the-box support:
- Support for UNIX / Windows PC and WindRiver VxWorks
- Transport layers included: Serial RS-232, TCP/IP
- Can customize your own transport layer, API available for this
External Mode Demo
Video of External Mode
HW connectivity support
Pixhawk Target

- Open source hardware for all sorts of the amateur/commercial micro-UAVs
- Highly customizable hardware. Can be used with quad-copter, hexa-copter or fixed wing UAVs
- Runs a Real-Time Operating System (NuttX) on ARM Cortex-M.
- Simulink code generation target written by Steve Kuznicki (Pilot Engineering). Tested with a hexa-copter
- AR Drone and Pixhawk Target Support package coming soon!
Resources
Community, Support, and Add-Ons

http://www.mathworks.com

- Seminars
- Webinars
- Workshops
- Videos
- Examples

- Technical Support
- Pilot Engineering
- Training
- Consulting
- Book Program

- File Exchange
- MATLAB Answers
- Apps
- Hardware support packages
Improved productivity and effectiveness

- Accessing data
- Exploring, analyzing, and visualizing data interactively
- Automating common tasks
- Debugging and optimizing code
- Sharing results
- Discovering new features and capabilities
Technical Support

Resources
- support@mathworks.com
- Over 100 support engineers
  - All with MS degrees (EE, ME, CS)
  - Local support in North America, Europe, and Asia
- Comprehensive, product-specific Web support resources

High customer satisfaction
- 95% of calls answered within three minutes
- 70% of issues resolved within 24 hours
- 80% of customers surveyed rate satisfaction at 80-100%
MATLAB Central

- Open exchange for the MATLAB and Simulink user community
- 70,000 visits per day

- File Exchange
  - Access more than 10,000 free files, including functions, apps, examples, and models

- MATLAB Answers
  - Ask MATLAB questions or search more than 18,000 community-answered questions.

- Newsgroup
  - Web forum for technical discussions about MATLAB and Simulink
  - 1,400 posts per day

- Blogs
  - Read commentary from engineers who design, build, and support MATLAB and Simulink.

Based on average 2011 data
Training Services

Exploit the full potential of MathWorks products

Flexible delivery options:

- Public training available worldwide
- Onsite training with standard or customized courses
- Web-based training with live, interactive instructor-led courses
- Self-paced interactive online training

More than 30 course offerings:

- Introductory and intermediate training on MATLAB, Simulink, Stateflow, code generation, and Polyspace products
- Specialized courses in control design, signal processing, parallel computing, code generation, communications, financial analysis, and other areas
Consulting Services
Accelerate your return on investment

A global team of experts supporting every stage of tool and process integration
Questions?