Workflow for Control System Design and Implementation

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Agenda

- Industry Trends and Challenges
- Design PID Controller & Feedback Compensator
- Adding Control logic
- Implementing control algorithm
Challenge - Increasing Software Content

Software content increasing 3x – 5x per year
How to develop and manage such large amount of software?
Growth of Automotive Electronics and Software

- **Microcode/Assembly**
  - **Motorola 6800**
    - 8 bit / 1 MHz / 4 kBytes

- **Modeling**
  - C

- **Abstraction**

- **Processor**
  - Freescale MPC5674F
    - 32 bit / 200+ MHz / 4000 kBytes

- **Ignition**
- **Fuel Injection**
- **ETC**
- **GDI**
- **DCT**
- **HCCI**

Year:
- 1970
- 1980
- 1990
- 2000
- 2010
- 2020
Model-Based Design - Controller Design

- **Research**
- **Requirements**

**Design**
- Environmental Models
  - Mechanical
  - Electrical
- Control Algorithms
- Supervisory Logic

**Implementation**
- C, C++
- VHDL, Verilog
- Structured Text
  - MCU
  - DSP
  - FPGA
  - ASIC
  - PLC

**Integration**

**Test & Verification**
What is Our End Goal?

Embedded Processor or ECU
Problem Formulation

Higher Performance:

1. **Faster trajectory**
   - Vmax: 150 $\rightarrow$ 250 rad/s
   - Amax: 2000 $\rightarrow$ 5000 rad/s$^2$

2. **Decreased error at standstill**
   - error < 1 rad
Agenda

- Industry Trends and Challenges
- **Design PID Controller & Feedback Compensator**
- Adding Control logic
- Implementing control algorithm
Control Design: *solving your design problem*

- Tuning a PID controller
- Specifying the controller structure in Simulink
- Setting up your design environment
- Analyzing and tuning the closed loop
- Discretizing controller
- Optimizing design parameters
- Designing fault detection logic

Demo
PID Controller Block with Automatic Tuning

- Function Block Parameters: PID Controller
  - Controller: PD
  - Time-domain: Continuous-time
  - Filter method: Forward Euler
  - Sample time (-1 for inherited): Ts

- Tuning Interface:
  - Tuna... button
  - Interactive tuning:
    - Response time: 3.15 sec
    - Slower
    - Faster
  - Automatically update block parameters

- Graphs:
  - Step reference tracking
  - Amplitude over time
  - Tuned response

- Position and Position Error plots
Agenda

- Design PID Controller & Feedback Compensator
- Adding Control logic
- Implementing control algorithm
Designing Fault Detection Logic
Model-Based Design- Implementation

RESEARCH

REQUIREMENTS

DESIGN

Environmental Models

Mechanical

Electrical

Control Algorithms

Supervisory Logic

IMPLEMENTATION

C, C++

VHDL, Verilog

Structured Text

MCU

DSP

FPGA

ASIC

PLC

INTEGRATION

TEST & VERIFICATION
Agenda

- Design PID Controller & Feedback Compensator
- Adding Control logic
- Implementing control algorithm
Workflow for Control System Design - Implementation

Shobhit Shanker
Senior Application Engineer- Code Generation and Verification
Implement Model as Software On-target

Controller Model

Plant Model

Code Generation

Embedded Processor or ECU
Demo – Code Generation

```
/* MATLAB Function 'MATLAB Function' */
/* Simple fixed-point operation without saturation checking. */
if (rtwdemo_fixpt1_In1 > 0.0) {
  /* Output: '<Root>/Out1' */
  /* '<S22:118>' */
  rtwdemo_fixpt1_Out1 = rtwdemo_fixpt1_In1 * 3.2;
} else {
  /* Output: '<Root>/Out2' */
  /* '<S22:119>' */
  rtwdemo_fixpt1_Out2 = -rtwdemo_fixpt1_In1 * 3.2;
}
```
How Did We Get Here?
Workflow For Embedded Code Generation

Setting up Code Generation Environment
- Modeling Guidelines Checking
- Code Generation Advisor Settings e.g. RAM/ROM

Add Software Design Details
- Algorithm Partitioning e.g. reusable libraries, Model reference
- Data Typing, Scoping of Variables, Fixed Point Details, Sw-DD

Generate Code & Review
- Peer review, Code Walkthrough
- Standards Compliance e.g. MISRA-AC-AGC

Verification and Integration of Code
- Software-in-loop testing (SIL)
- Processor-in-Loop (PIL) for Target Testing
- Platform Integration
Setting up Code-Generation Environment

- Discretizing the model
  - Variable → Fixed-Step
- Code Advisor
- Float-Fixed point conversion
- Modeling guidelines checking MAAB, DO178B/C, ISO26262
Add Software Design Details

- Naming of Variable
- Storage class (Scope)
- Datatype
- Comments
- Algorithm Partitioning
  - Functions
  - Reusable Functions
  - Inline
  - #Pragmas
Generate Code and Review

- Traceability
- Static Code Metrics
  - RAM
  - Call Tree
  - SLOC
- Comments
Continuous Test and Verification (SIL/PIL)
Model Testing

- Develop test inputs
  - Types of inputs:
    - Functional requirement
    - High level use case
    - Sensitivity analysis
    - “Edge Case” testing
    - Robustness testing
    - …etc

- Apply the test inputs to model
- Analyze the results
  - Expected output
- Measure coverage
Log Signals of Interest

Identify numerical differences

Supports:
- Normal, SIL, PIL
- Logged signals
- Imported signals
- HTML reports
Software-in-the-Loop (SIL) Testing:
Verify Production Controller with Software-in-the-loop

Execution
- Host/Host
- Nonreal-time

Compiled C Code
S-Function
(Windows DLL)
Processor-in-the-Loop (PIL) Testing:
Verify Production Controller with Processor-in-the-loop

Execution
• Host/Target
• Nonreal-time
Platform Integration

Controller Model

Communication Interfaces

Sensors

Comm Drivers

Generated Algorithm Code

Input Drivers

Optional Target Optimized Code

Output Drivers

Special Device Drivers

Scheduler/Operating System and Support Utilities

Generated Algorithm Code

Input Drivers

Output Drivers

Special Device Drivers

Scheduler/Operating System and Support Utilities

Communication Interfaces

Sensors

Actuators

Special Interfaces

Tuning
Summary

- Design, Tune and Test Controllers in Simulink
- Convert Controller Models to Embedded Code
- Test Generated Code on Target
What’s Next?

- Explore >> rtwdemos
- Attend Embedded Code Generation class
  www.mathworks.com/services/training/courses/SLEC_1.html
- Request Advisory Services: Developing Embedded Targets, Model-Based Design for ISO 26262 or DO-178
  www.mathworks.com/services/consulting/areas/design.html
- Read Technical Articles and User Examples
  www.mathworks.com/programs/techkits/pcg_tech_kits.html

Thank You!