Home Appliance Controls Development using Model Based Design

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About Whirlpool

- World’s leading major Home Appliance company
- Founded over 100 years ago
- ~$21 billion in revenue in 2018
- 92,000 employees and 70 manufacturing and technology research centers
- 1 in 3 employees volunteer for taking care of our neighborhoods and the planet
### Limitations of Traditional Software Development Process

**The Waterfall Model**

- **Poor Requirements Management**
  - Missing linkage between requirement and software code.
  - Unfreeze requirements

- **Manual Code Implementation**
  - Squeezed timelines.
  - Software Integration with cross regional teams in workforce.
  - Less readability, difficult debugging
  - Variation in implementation method from developer to developer.

- **Hardware requirement for Verification**
  - Setup & Maintenance Cost Involved.
  - Difficult setup replication.
  - Hardware availability.
  - Safety of Tester.
MBD process in Whirlpool....Few years Ago

**Control Model Development and Code Generation**
- Model development in Simulink using Stateflow
- Primary level verification using Signal Builder and m-scripts.

**Rapid Control Prototype**
- Data acquisition during development phase of control model
- Model verification on machine without dependencies on other software components

**MIL/SIL**
- Design error checks
- Black Box & White Box Testing for control model
- Both Unit Level and Integrated Level Testing
- Coverage Report Analysis

**PLANT MODEL FOR CLOSED LOOP MIL/SIL**
- Leveraging physics based Plant Model for closed loop simulation

**Requirements**

**Challenges**
- Direct deployment on machine for testing
- Hardware setup issues
- Safety concerns
- Delayed testing due to other software dependencies

- Hardware dependency and setup issues

- Unavailability of Model Requirements
- Unavailability of inputs that replicate system behaviour (Level Testing)
Current MBD Workflow in Whirlpool

Requirements

Plant Model
- FMI Toolkit

MIL/ SIL
- Simulink V&V, SLDV

Control Model
- Stateflow, Fixed Point Designer

Rapid Control Prototype
- Embedded Coder

Code Generation & Integration
- Embedded Coder
- Stateflow, Fixed Point Designer

Verification on machine
- Whirlpool Corporation

Whirlpool Corporation - Confidential
Summary of MBD algorithm in different whirlpool products
Universal Motor Controls Development

- Requirements breakdown
- Class Diagrams for Controller using SysML
- System Engineering Support for development of Universal Motor Plant Model
- Verification at Module level as well as integrated level.
Algorithm Modeling Using Stateflow & Simulink

- Algorithm requirements have been implemented as a Simulink® model
  - Floating/Fixed point, Fixed step size
  - Use most convenient tools (Simulink, Stateflow, MATLAB code blocks)
  - Use referenced model
  - Use of Data Dictionaries
  - Capturing Model Metrics
  - Traceability
Universal Motor and Washer Dynamics Plant Model

Plant Model Development

- Model Based System Engineering team support for Plant Model Development
- Use of Dymola/Modelica environment
- Calibration of Plant Parameters with Real Time Test Data

Open Loop Validation

Closed Loop Validation with Basic Control
Integration of Control Model and Plant Model

- Use of Functional MockUp units for leveraging Dymola Plant Models in Simulink
- Provides Capability to find robustness of the logic at system level.
- Allows to perform System Level verification

Simulink PSP Toolbox till 2016
Inbuilt Simulink FMI kit feature 2017 onwards
Verification and Validation

- Test Case Generation in RQM
- Prepare Test Cases for Simulink models linked with DNG Requirement

Simulink Model
- Model Requirements in DNG
- Raising defects in RTC and updating results in RQM

Simulink Design Verifier
- Automatic Design Error Check
- Harness model allows testing the component in simulation

Coverage Analysis
- Matching coverage, condition coverage, MC/DC coverage

Simulink Coverage & Test
- Test Report From Simulink Test
- Produces report analysing Pass/Fail conditions.

Simulink V&V
- Simulink Design Verifier
- Simulink Model
- Test Harness
- Coverage Report by Model
Requirement Linking from Simulink to DNG

Configure Requirement Settings

Select Project Area from DNG

Selecting Requirement from DNG

DNG Link of requirement in Simulink

Simulink Implemented link in DNG

Simulink Requirement Toolbox
Application of Simulink V&V & Design Verifier

1. Cumulative coverage results on multiple tests

   ![Coverage Table]

2. Identified missing coverage

   ![Overflow Detection Diagram]

3. Traceability between DOORS requirements and Model

   ![Traceability Diagram]
Code Generation and Integration

- Toolboxes Used:
  - Stateflow
  - Embedded Coder
  - Fixed Point Designer
  - Matlab coder
  - Simulink Coder

- Variant Subsystems
- Auto-Code Generation
- Interface Code

Delivery of complete package to the stream

Achieving Optimized Code: (reference MATLAB EXPO 2018)

- Use of Model Advisor to apply and establish best Modeling practices
  - MAAB/MISRA C, ISO/IEC Standards etc
  - Simulink and Stateflow guidelines

- Model Advisor Guidelines
  - Modeling Standards for DO-178C/DO-331
  - Modeling Standards for EN 50128
  - Modeling Standards for IEC 61508
  - Modeling Standards for IEC 62304
  - Modeling Standards for ISO 26262
  - Modeling Standards for MAAB
  - Modeling Standards for MAAE
  - Modeling Standards for MISRA C:2012

Optimizations For Target
Configurations For Code Generation

Execution Speed

RAM ROM
Advantages of Model Based Design

- Consistent design flow from conception to implementation using same language
- Detecting errors in early stages of Software Development
- Easy to deploy code in different projects by managing variant subsystems.
- Easy to handle change requests without impact on timelines.
- Very few defects in released softwares
- Early observation for unexpected emergent behavior.
- Good Test Management
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