Converting Legacy Embedded Control Software to Executable Specifications

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Power Train Requirements are becoming increasingly strict.

- Fuel Economy
- Clean Exhaust Gas Emission
- Performance (e.x. Drivability)

Increasing complexity of Engine Control Algorithms

Development process improvement is an urgent issue.

Keywords: Model-Based Development (MBD)
MBD Concept

Virtual World

Engine Performance Specification II

Validation

Combination

Control Software Specification II

Controller Model

Engine Model

SILS

Real World

Engine (Engine, Actuators, Sensors)

Rapid Prot. ECU

Controller (Hardware, Software)

HILS

Combination

Validation
Major Activities in MBD

- Model-Based Control
- Model-Based Calibration
- Model-Based Verification & Validation
- Rapid Modeling
- Executable Specification
- Automatic Code Generation (ACG)

TOYOTA and DENSO have already deployed an ACG environment using Real-Time Workshop Embedded Coder® for advanced and mass production development.


Focus: Executable Specification
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Executable Specification

20 to 30% of development period have been reduced.
(Executable Specification + ACG)

NOTE: Executable specifications are applied to roughly 10% of engine control algorithms.
Motivation

In order to shift to MBD entirely (i.e., further improvements in productivity), we started a project to convert documented legacy control algorithms into executable specifications.
Expectation

Converted Controller Models

Development in the virtual world
- Control algorithms can be explored using controller models and plant models.

Maintenance
- MBD process can be adopted for the maintenance of legacy control algorithms.

Other Activities
- Controller models enable re-architecting the control modules software efficiently.
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Key Considerations

- Correct models
- Uniform quality
- Readable models
- Uniform appearance of models
- Efficient conversion methodology

Key to success: - Structured Process
- Automation
Basic Idea of Conversion

“Legacy Embedded Software”

C-code

Conversion

Simulink Model

“Executable Specification”

Documents

“Properties for Parameters”
“Compiler Configurations”
“Style Guidelines”
“Conversion Rules” etc.

Additional Information
Conversion Process

Start -> Architecture Extraction

Model Implementation -> Test Vector Generation

Architecture Extraction -> Verification & Peer Review

Verification & Peer Review -> Product Release

Product Release -> Update Knowledge Base

C-code -> Simulink Model

Direct Path

Conditional
Key Features of Process

- Structured process
- Parallel works
- Automation throughout the process
- Continuous improvement ("Kaizen")

Similar to "Assembly Line"

This process is very efficient while delivering good quality.
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Model Implementation

Target models and modeling
- Correct
- Readable
- Uniform
- Efficient

Process rules and Trained engineers

- Automation scripts
- Custom block sets
- Style guidelines
- Style checkers

Start
C-code
Architecture Extraction
Model Implementation
Test Vector Generation
Verification & Peer Review
Product Release
Simulink Model

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Quality Control

Guarantee of the model quality
- Correct
- Readable
- Uniform
- Efficient

"numerical correctness"
"functional accuracy"
"adherence to style guidelines"

- Verification technologies
- Peer review

Process rules and Trained engineers

Guarantee of the model quality

- Verification & Peer Review

- Test Vector Generation

- Model Implementation

- Architecture Extraction

Start

C-code

Simulink Model

"numerical correctness"
"functional accuracy"
"adherence to style guidelines"

- Verification technologies
- Peer review

Process rules and Trained engineers
Meaningful test vectors must be found efficiently.

- TVG is constructed from automatic data generation and manual activity.
- Automatic generation of static signal step tests is used.
- Original coverage metrics are applied.
- TVG continues until coverage requirements are met.
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Current Plan

Aim: Two times increase of productivity

with other activities in MBD

Engine control algorithm specifications

Documented spec. Model implemented spec.

Current After several years

0 100%
Future Works

- Continuous improvement of the conversion process
  efficient and practical verification tools environment

- Large scale modeling
  practical environment, style guidelines

- Integrated development environment
  tool chain enhancement
Conclusions

- Due to further improvements in productivity, TOYOTA started a project to convert documented legacy algorithms into executable specifications.

- Adherence to a structured process is one of the key enablers for the successful execution of this project.

- The result of this project will bring about great improvements to the power train control system development process in TOYOTA.
Thank you for your attention!