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
- Engine Model
- Controller Model
- Engine (Engine, Actuators, Sensors)
- Controller (Hardware, Software)

Validation
Combination

Rapid Prot. ECU
HILS
SILS

Real World
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**

- MBD Application to power train control ECU software
  - Advanced development
  - Production development

- Execution period:
  - 2000
  - 2002
  - 2004
  - 2006

- Executable Specification
  - + ACG
  - + Hand written code

- Deployment of Simulink® models as production specifications

- 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
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
  - Simulink Model
  - Architecture Extraction
  - Test Vector Generation
  - Verification & Peer Review
  - Product Release
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

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