dSPACE Embedded Success

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Overview

- What is EcoCAR?
- Vehicle Architecture
- Guided by Model-Based Design
- xIL Process
- Real Time Development and Data Analysis
- Future Work
What is EcoCAR 3?
4-year Advanced Vehicle Technology Competition (AVTC) challenging 16 college teams to rebuild a 2016 Chevrolet Camaro

Engineering Goals:
- Increase fuel economy
- Reduce emissions and energy consumption
- Maintain performance and consumer acceptability
History

A History of Performance

- **ChallengeX**
  - Year 1 - 2005: 3rd Place
  - Year 3 - 2007: 4th Place

- **ChallengeX**
  - Year 2 - 2006: 4th Place
  - Year 4 - 2008: 3rd Place

- **EcoCAR 1**
  - Year 1 - 2009: 1st Place
  - Year 3 - 2011: 2nd Place
  - Year 2 - 2010: 5th Place

- **EcoCAR 2**
  - Year 1 - 2012: 2nd Place
  - Year 3 - 2014: 1st Place

- **EcoCAR 3**
  - Year 1 - 2015: 1st Place
  - Year 3 - 2017: 1st Place
  - Year 2 - 2016: 1st Place
Four Year Competition

Year One: 0 Buyoff
• Design the car
  • Choose engine, transmission, other key components

Year Two: 50% Buyoff
• Build the car
  • Received car in December 2015
  • Had three months to completely rebuild as a hybrid vehicle

Year Three: 65% Buyoff
• Refine the car
  • Work out all bugs and problems in car
  • Begin to tweak vehicle and its systems to achieve maximum performance and efficiency
  • Test emissions and energy usage

Year Four: 99% Buyoff
• Refine and Optimize the car (cont.)
  • Ensure car drives and feels as good as one just bought from a showroom
  • Tweak vehicle and its systems to achieve maximum performance and efficiency
EcoCAR Competition Industry Benefits

• Increases interest in the automotive industry
• Gives students a hands-on experience to apply knowledge learned in the classroom, that better prepares them to be automotive engineers of the future
• Opportunity to work in a cross functional team
  • High level understanding of how different subsystem and components work together within the vehicle
• Prepares students for full-time employment
  • Works with Industry sponsored software (NX for Design, Simulink, dSPACE, etc)
  • Instills troubleshoot and problem solving skills
Vehicle Architecture
Ohio State EcoCAR 3 Vehicle Architecture

Parallel – Series Plug-in Hybrid Electric Vehicle

32 kW Denso ISG Belted Alternator Starter

2.0L E85 Engine (119kW)

112 kW Peak Power Parker Hannifin Electric Machine

18.9 kWh A123 Lithium Ion Battery Pack

5-Speed Tremec Automated Manual Transmission
Vehicle Technical Specifications (VTS)

**Increase Fuel Economy**
- 40MPGge
- 40 Miles of all electric range
- 250 Miles of total range

**Reduce Emissions**
- Uses E85
- Estimated 50-70% emissions reductions

**Maintain Performance**
- 0-60 time of 6.6 seconds
- 340 horsepower
Guided by Model-Based Design
“the development process centers around a system model – from requirements capture and design to implementation and test.”
Core Concepts of Model-Based Design

- Define Requirements
- System-Level Specifications
- Subsystem Design
- Subsystem Implementation
- Complete Integration & Test

Continuous Engineering

- Physical Modeling, Algorithm Development, Simulation, etc.
- Rapid Prototyping, Embedded Code Generation, etc.
- Requirements Traceability
- Finalize architecture design

99% mule vehicle by competition

Subsystem build and vehicle integration

Model Coverage, Model Advisory, etc.

Component testing

System Definition (MLU)

Time

Define Requirements
System-Level Specifications
Subsystem Design
Subsystem Implementation
Complete Integration & Test

Rapid Prototyping, Embedded Code Generation, etc.
### Design Failure Mode and Effects Analysis (DFMEA)

<table>
<thead>
<tr>
<th>Line No.</th>
<th>Item / Function of the Part</th>
<th>Potential Failure Mode (Loss of Function or value to customer)</th>
<th>Potential Effect(s) of Failure</th>
<th>Potential Cause(s) / Mechanism(s) of Failure</th>
<th>O C C</th>
<th>Current Design Controls (Design actions planned or completed to prevent or reduce occurrence of failure, provide details and Best Practices used)</th>
<th>Current Design Controls (Analytical or physical validation method planned or completed)</th>
<th>D E T</th>
<th>RPN</th>
<th>Recommended Action(s)</th>
</tr>
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<tbody>
<tr>
<td>3</td>
<td>[1] Clutch transfers engine torque to transmission</td>
<td>[1.2] Clutch engages without request</td>
<td>Unintended engine start or incorrect engine speed match</td>
<td>[1.2.1] Controller error</td>
<td>7</td>
<td>Engine and transmission speed sensors</td>
<td>Controller tested on HIL</td>
<td>2</td>
<td>98</td>
<td>[1.2.1.1] Shut down front powetrain and shift transmission into neutral</td>
</tr>
<tr>
<td>4</td>
<td>[1] Clutch transfers engine torque to transmission</td>
<td>[1.2] Clutch engages without request</td>
<td>Unintended engine start or incorrect engine speed match</td>
<td>[1.2.2] Voltage supply out of range</td>
<td>2</td>
<td>Fault monitoring from master cylinder</td>
<td>Regular charging and monitoring of battery voltage</td>
<td>2</td>
<td>28</td>
<td>[1.2.2.1] Shut down front powetrain and shift transmission into neutral</td>
</tr>
<tr>
<td>5</td>
<td>[1] Clutch transfers engine torque to transmission</td>
<td>[1.3] Clutch slips between input and output</td>
<td>Less power transferred from engine to transmission and possible clutch damage</td>
<td>[1.3.1] Controller error</td>
<td>7</td>
<td>Engine and transmission speed sensors</td>
<td>Frequent check of clutch material and actuator</td>
<td>3</td>
<td>147</td>
<td>[1.3.1.1] Disengage clutch</td>
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<tr>
<td>6</td>
<td>[1] Clutch transfers engine torque to transmission</td>
<td>[1.3] Clutch slips between input and output</td>
<td>Less power transferred from engine to transmission and possible clutch damage</td>
<td>[1.3.1] Insufficient Clutch Pressure</td>
<td>8</td>
<td>Engine and transmission speed sensors</td>
<td>Frequent check of clutch material and actuator</td>
<td>3</td>
<td>168</td>
<td>[1.3.1.1] Disengage clutch</td>
</tr>
<tr>
<td>7</td>
<td>[1] Clutch transfers engine torque to transmission</td>
<td>[1.3] Clutch slips between input and output</td>
<td>Less power transferred from engine to transmission and possible clutch damage</td>
<td>[1.3.2] Damaged clutch actuator</td>
<td>4</td>
<td>Engine and transmission speed sensors</td>
<td>Frequent check of clutch material and actuator</td>
<td>3</td>
<td>126</td>
<td>[1.3.2.1] Disengage clutch</td>
</tr>
<tr>
<td>8</td>
<td>[1] Clutch transfers engine torque to transmission</td>
<td>[1.3] Clutch slips between input and output</td>
<td>Less power transferred from engine to transmission and possible clutch damage</td>
<td>[1.3.3] Damaged clutch actuator</td>
<td>4</td>
<td>Engine and transmission speed sensors</td>
<td>Frequent check of clutch material and actuator</td>
<td>3</td>
<td>84</td>
<td>[1.3.3.1] Disengage clutch</td>
</tr>
<tr>
<td>9</td>
<td>[1] Clutch transfers engine torque to transmission</td>
<td>[1.4] Clutch input shaft yields</td>
<td>Less power transferred from engine to transmission and possible clutch damage</td>
<td>[1.4.1] Sudden high input torque (from electric machine)</td>
<td>2</td>
<td>Torque feedback from inverter</td>
<td>Impose torque limits on clutch inputs, ramp torque during electric start</td>
<td>3</td>
<td>42</td>
<td>[1.4.1.1]</td>
</tr>
<tr>
<td>10</td>
<td>[1] Clutch transfers engine torque to transmission</td>
<td>[1.5] Clutch catastrophic failure</td>
<td>Engine cannot transmit power to transmission</td>
<td>[1.5.1] Engine speed exceeds clutch limit</td>
<td>2</td>
<td>Transmission speed sensor</td>
<td>Impose speed limits on clutch inputs</td>
<td>2</td>
<td>28</td>
<td>[1.5.1.1]</td>
</tr>
<tr>
<td>11</td>
<td>[1] Clutch transfers engine torque to transmission</td>
<td>[1.6] Clutch over heats</td>
<td>Internal components fail</td>
<td>[1.6.1] Excessive power input at high ambient temperature</td>
<td>7</td>
<td>Master cylinder temperature sensor</td>
<td>Measure temperature frequently</td>
<td>3</td>
<td>63</td>
<td>[2.4.1.1] Shift transmission into neutral</td>
</tr>
<tr>
<td>13</td>
<td>[2] Transmission applies reduction ratio from input torque and transfers to the wheels</td>
<td>[2.2] Input shaft yields</td>
<td>Transmission is inoperable</td>
<td>[2.2.1] Excessive input torque</td>
<td>2</td>
<td>Electric motor and transmission speed sensors</td>
<td>Controllers tested on HIL</td>
<td>3</td>
<td>42</td>
<td>[2.2.1.1] Shift transmission into neutral</td>
</tr>
</tbody>
</table>
System Safety Requirements

1. Introduction

1.1 Purpose of the Document

Outline of requirements related to the functional safety algorithm in the HSC

1.2 Definitions, Acronyms, and Abbreviations

- APP: Accelerator Pedal Potentiometer
- BPP: Brake Pedal Potentiometer
- FMF: Fault Monitoring/Management
- TS: Torque Sensory
- PTN: Pass Through Neutral
- Acceleration: Vehicle acceleration with a positive vector in the current direction of motion
- Driver Gear: PRNDL position Drive or Reverse
- Forward/Backward: Forward and backward apply for a driver sitting at the steering wheel

2. Fault Detection/Diagnostics

2.1 Brake Pedal

2.2 PRNDL

- PRNDL functional safety algorithm shall detect when the PRNDL sensor LOW is not between .40 V and 1.9 V within 20 milliseconds after the HSC receives the voltage signal and shall set PRNDLFault == 1
- PRNDL functional safety algorithm shall detect when the PRNDL sensor HIGH is not between .55 V and 2.0 V within 20 milliseconds after the HSC receives the voltage signal and shall set PRNDLFault == 2
- PRNDL functional safety algorithm shall detect when the PRNDL sensor LOW and HIGH are not between 0.40 V and 1.9 V, and 0.55 V and 2.0 V respectively within 150 milliseconds after the HSC receives the voltage signal and shall set PRNDLFault == 3
- PRNDL functional safety algorithm shall detect when there is a scaling error between PRNDL sensor LOW and HIGH of more than 2.5% within 100 milliseconds after the HSC receives the voltage signal and shall set PRNDLFault == 4

2.3 APP

- APP functional safety algorithm shall detect when APP sensor LOW is not between .5 V and 2.18 V within 20 milliseconds after the HSC receives the voltage signal and shall set APPSensorFault == 1
- APP functional safety algorithm shall detect when APP sensor HIGH is not between .905 V and 4.335 V within 20 milliseconds after the HSC receives the voltage signal and shall set APPSensorFault == 2
- APP functional safety algorithm shall detect when there is a scaling error between APP sensor LOW and HIGH within 200 milliseconds after the HSC receives the voltage signals and shall set APPScalingFault == 1
- APP functional safety algorithm shall detect when APP sensor LOW is transmitting a STUCK signal within 0.5 seconds after the HSC receives the voltage signal
xIL Process
MIL, SIL, HIL/CIL, VIL
Regression Testing

- Ensure validation through increasing fidelity levels
- Ensure logic robustness and catch bugs before being implemented on vehicle
Modular Structure

• The full vehicle model is setup in a modular manner

• Setup is easy to transfer from MIL to SIL/PIL/HIL/VIL:
  • The Inputs and Outputs layer are completely separated from the Algorithm part of the models to separate out Electrical and CAN interfacing

• Communication between supervisory, GCM and the powertrain/components in MIL/SIL:
  • From-goto block-set
  • Vehicle Network Toolbox (allows use of .dbc files in MIL phase)

• Communication between supervisory and the powertrain/components in HIL:
  • RTI block-set, Motohawk block-set is used for the GCM and other controllers
Plant model structure

COMMUNICATIONS INTERFACE

Electrical Rx
RTI Multi I/O Blocks

SPINE

Inputs

Outputs

Electrical Tx
RTI Multi I/O Blocks

CAN Rx
RTI CAN Rx/Unpack Blocks

CAN Tx
RTI CAN Pack/Tx Blocks

LOGIC

INPUTS

CONTROLLER / PLANT MODEL

OUTPUTS
MIL to HIL Transition

Step 1: Conversion using an .m file within Simulink

C-code within Simulink (MABx)

C-code within Simulink (GCM)

Model Within Simulink

Controller (MABx + GCM)

Powertrain + Driver

1 Simulink Model

SIL

Step 2: Build Code for controllers using Simulink coder

C-Code within MABx II

Code Within GCM

C-Code within Midsize HIL Simulator

Controller (MABx + GCM)

Powertrain + Driver

3 Simulink Models

HIL

Step 2: Build Code using rti1401, motohawk rpc and rti1006
Emulated Soft ECUs

- The SMS team is emulating all the ECUs that are either team developed or team added in their full vehicle model.
SMS Testing Procedure

**MIL/SIL**
- Matlab/Simulink
- IBM Rational Doors
- Requirements Generation/Refinement

**PIL/HIL**
- ControlDesk
  - Hardware Software Interface
  - Recorded Data
  - Experiment Setup
- AutomationDesk
  - Test Case Generation and Execution
  - Recorded Data
  - Execution Plan
- Synect
  - Test Case/Verdict Management
  - Verdict/Results

Initiation → Requirements Generation/Refinement → Matlab/Simulink (Simulink Coder Built Code) → ControlDesk → AutomationDesk → Synect → Recorded Data → Execution Plan → Experiment Setup → Recorded Data → Execution Plan → Requires → Requirements Generation/Refinement → Initiation
Test Case Example

TransmissionFailure_Electrical (Sequence)

Name: TransmissionFailure_Electrical
Hierarchy: Y3_CompetitionDemo.TransmissionFailure_Electrical
Start time: 2017-05-06 09:39:01
Stop time: 2017-05-06 09:40:16
Execution duration: 74.134 sec.
Author: EcoCAR_HIL

Description:
The script injects electrical faults using the FIU to cut off power supply to the Shifting unit controller. The supervisory controller should detect that the shifting unit is no longer powered.

TransmissionFailure_Electrical
Real Time Development and Data Analysis
Rapid Prototyping

- Plant models validated through component and vehicle level testing
- Component Level Validation
  - Friction clutch – characteristic maps
  - Clutch Line pressure
  - Transmission – Shift times
PTU Thermal Testing and Analysis

• Sought to better understand the effects of the high speed operation of the PTU on oil temperatures

• Instrumented the PTU and differential with in oil sensor and recorded temperatures over the EEC drive cycles

• Data collected via Arduino interfaced with matlab
Data Analysis: Acquisition

**MIL**
- Excel data sheets, etc.

**HIL**
- ControlDesk NG
- Matlab Script
  *(Read/Post-Process)*
- Matlab Workspace

**VIL**
- MABx
- Vector gl100 data logger
CD Mode (MIL Simulation vs. Test data)

Energy Consumption from HIL Simulation – 6382 Wh
# Data Analysis

<table>
<thead>
<tr>
<th>Dates</th>
<th>Test</th>
<th>Hrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/25-26</td>
<td>TRC VDA</td>
<td>24</td>
</tr>
<tr>
<td>4/1-2</td>
<td>TRC VDA</td>
<td>24</td>
</tr>
<tr>
<td>4/7</td>
<td>TRC Emissions Lab</td>
<td>5</td>
</tr>
<tr>
<td>4/7-9</td>
<td>TRC VDA</td>
<td>36</td>
</tr>
<tr>
<td>4/15-16</td>
<td>TRC VDA</td>
<td>24</td>
</tr>
<tr>
<td>4/21</td>
<td>TRC Emissions Lab</td>
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<td>4/19</td>
<td>TRC HS Oval</td>
<td>12</td>
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<tr>
<td>4/21-23</td>
<td>TRC VDA</td>
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<td>4/28-30</td>
<td>TRC VDA</td>
<td>36</td>
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<td>5/1-3</td>
<td>TRC VDA</td>
<td>36</td>
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<tr>
<td>5/1</td>
<td>TRC Emissions Lab</td>
<td>5</td>
</tr>
<tr>
<td>5/4</td>
<td>TRC Emissions Lab</td>
<td>5</td>
</tr>
</tbody>
</table>

**Total Hrs** | **248**
Future Work
ADAS Algorithms

• Steps:
  1. Setup parameters
     • Line detection
     • Object detection
  2. Capture stereo images
  3. Rectify stereo images
  4. Detect lanes
  5. Detect objects
  6. Estimate distance to objects
  7. Overlay detection boxes and labels on output image
  8. Log data
  9. Display output image
 10. Repeat steps 2 - 9
Exploring MotionDesk for ADAS Testing
Thank You
Questions