Emulation of Aerospace Actuation Systems

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Project Relevance

- Woodward, Inc. is validating an electrical drive alternative to replace current thrust reverser actuation systems
- Replacing hydraulically/pneumatically powered parts with electric drive systems can result in the following benefits:
  - Reduced weight
  - Reduced maintenance
  - Additional data analytics for real-time system prognostics
- A controller hardware in the loop (CHIL) platform allows for verification of these claims without incurring excessive research/dev costs

Main Project Goals

- ☑ Create a modular CHIL system for use by current & future CSU project teams, specifically the EMTRAS project
- ☑ Determine analog & digital I/O requirements for the microcontroller and OPAL-RT interface
- ☑ Develop C code to run a closed-loop CHIL experiment on a real-time DC machine system model loaded onto the OPAL-RT
- ☑ Create a GUI in LabVIEW to view real-time outputs from the system under test

Stretch Goals

- ☑ Construct a 3D printed enclosure to neatly organize the physical HIL architecture
- ☑ Document all design steps and experimental results in detailed report packages
- ☑ Include system requirements flow-through and design information using the principles of model-based systems engineering (MBSE)
- ☐ [IN WORK] Design a PI control loop to generate/validate stable outputs from the OPAL-RT, then verify through unit testing

Budget

Item	Cost (with S/H)	Order Date
BNC-miniBNC Connector	($7.63)	9/21/2021
TI Microcontroller (x2) & Dev Board (x1)	($515.23)	2/18/2022
DB9 Connectors & Fasteners	($15.05)	4/1/2022
E-Days Materials	($61.77)	4/11/2022
Total Starting Budget	$600.00	
Total Expenses	($599.68)	
Total Ending Budget	$0.32	

Physical HIL Architecture

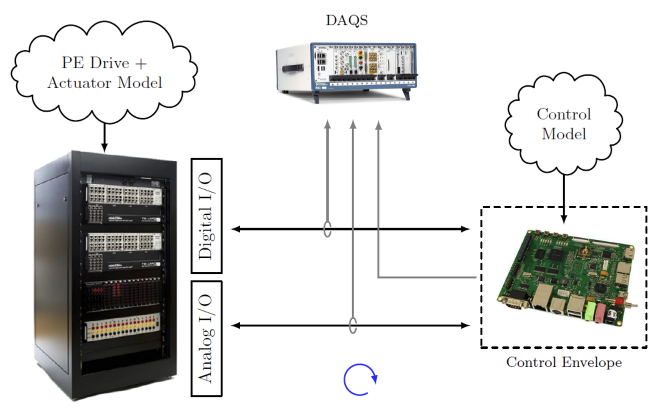


Fig. 1 – CHIL System Architecture

Hardware Elements:

- TI TMS320F28379D Microcontroller & Dev Board
- OPAL-RT 5620
- NI cRIO Controller
- 3D Printed Microcontroller Enclosure
- DB9 Wire Harness

Constraints:

OPAL 5600 RT Machine	TI TMS320F28379D

• I/O: -30V to 30V
• OPAL 5620 8 I/O Flat Carrier:
  ◦ output: +/- 12VDC @ 1.2A (mezzanine A/B)
  ◦ output: +/- 18VDC @ 0.8A (mezzanine A/B)
  ◦ input: +/- 12VDC @ 6A; +/- 5VDC @ 3A
• OPAL 5142 Digital I/O: 0-3 V
• Onboard XILINX Spartan 3A FPGA: 3.3V (LVTTL)
• 12 nodes maximum
• Requires miniBNC connector
	• 3.3V I/O design
	• -0.3V min to 4.6V max (0-3.3 V nominal operating range)
	• -20mA to 20mA
	• 50 kHz synchronization rate
	• Requires code written in C (no object-oriented functionality)
	• Requires code to be written in the TI Code Composer Studio IDE

Prototype Evolution:

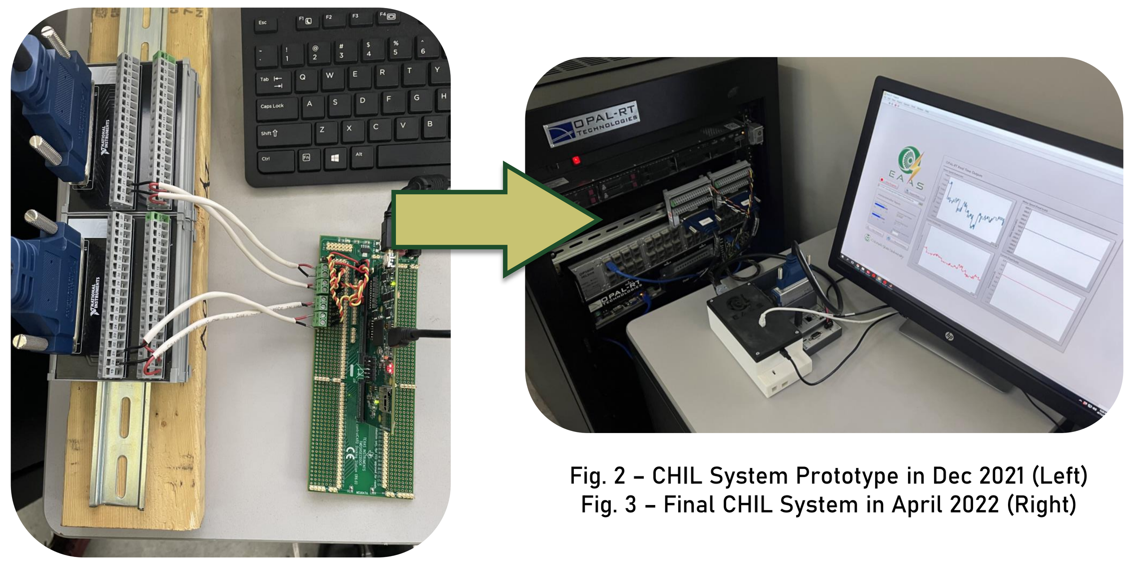


Fig. 2 – CHIL System Prototype in Dec 2021 (Left)
Fig. 3 – Final CHIL System in April 2022 (Right)

Required/Acquired Skills

- Embedded Systems/Control Algorithms in C
- MATLAB/Simulink
- HIL Construction and Interfacing
- LabVIEW GUI Design
- System Modeling Using MBSE Practices
- Defining/Testing GPIO Interfaces
- 3D Printing

Software HIL Architecture

Inputs to OPAL-RT (0-3 V)

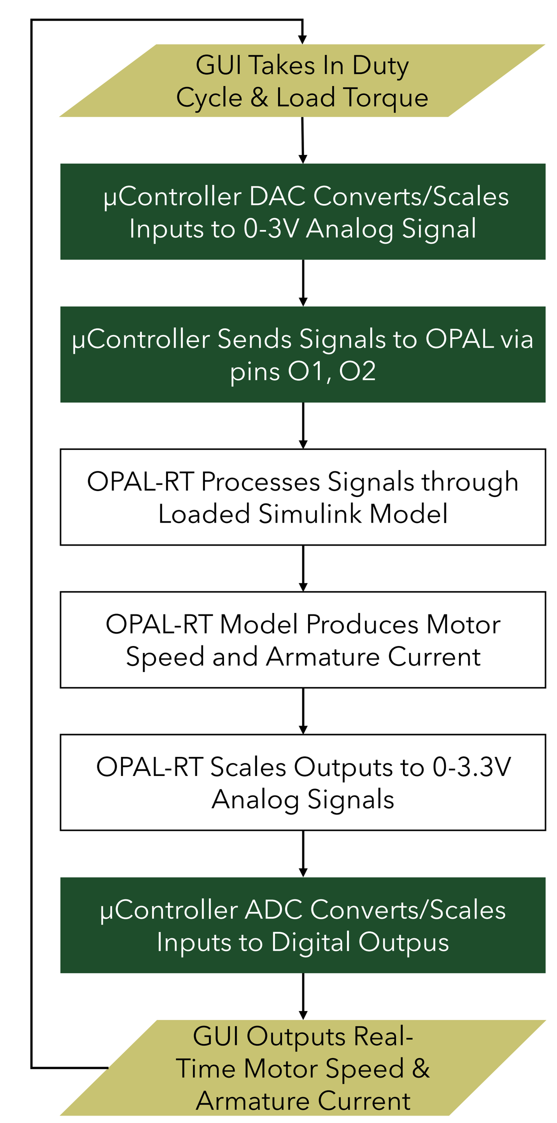
- Duty Cycle [0 to 100% +/- 3%]
- Load Torque [-0.2 Nm – 0.2 Nm +/- 3%]

Outputs from OPAL-RT (0-3.3 V @ 20 mA)

- Motor Speed [-600 to 600 rad/s +/- 3%]
- Armature Current [-2.5 to 2.5 A +/- 3%]

Software Elements

- µController Code, OPAL-RT Model, LabVIEW GUI



Pin	Function
I1	Armature Current
I2	Motor Speed
O1	Duty Cycle
O2	Load Torque

Table 1 – GPIO Microcontroller Pins

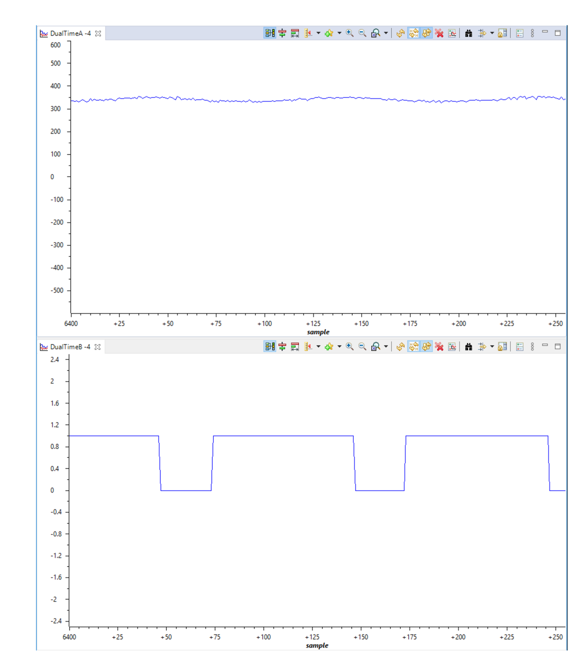


Fig. 4 – Real-Time Armature Current (Top) and Motor Speed (Bottom)

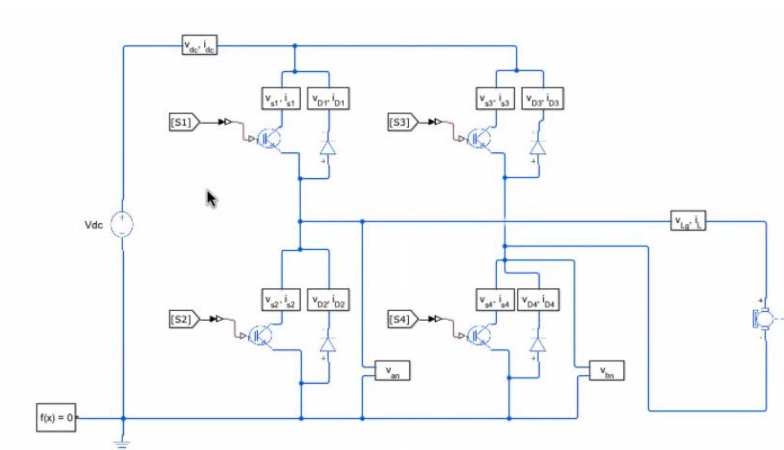


Fig. 5 – Simulink DC Machine Model

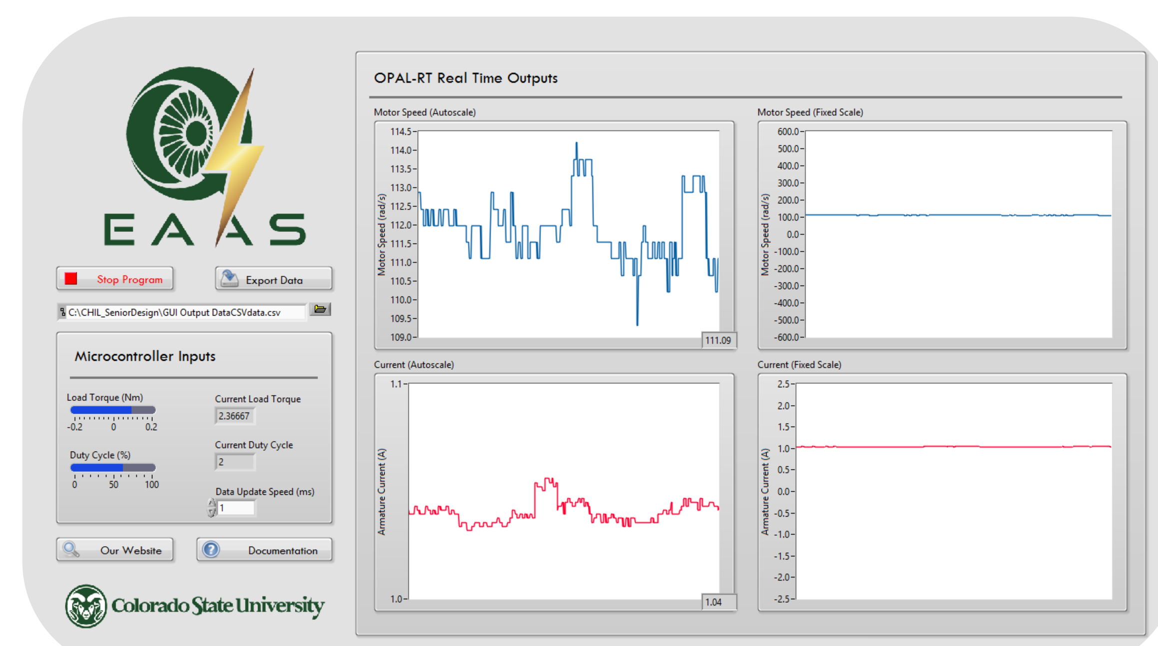


Fig. 6 – LabVIEW-Based CHIL GUI

Model-Based Systems Engineering

- Team followed the MBSE process to create a verifiable and easily upgradable system
- Defined a set of 25 functional/non-functional requirements according to INCOSE standard
- Modeled various viewpoints of the system using Use Case Diagrams, Sequence Diagrams, & Internal Block Diagrams in Cameo Systems Modeler
- Used Cameo Systems Modeler as central repository of system design information, accelerating project completion

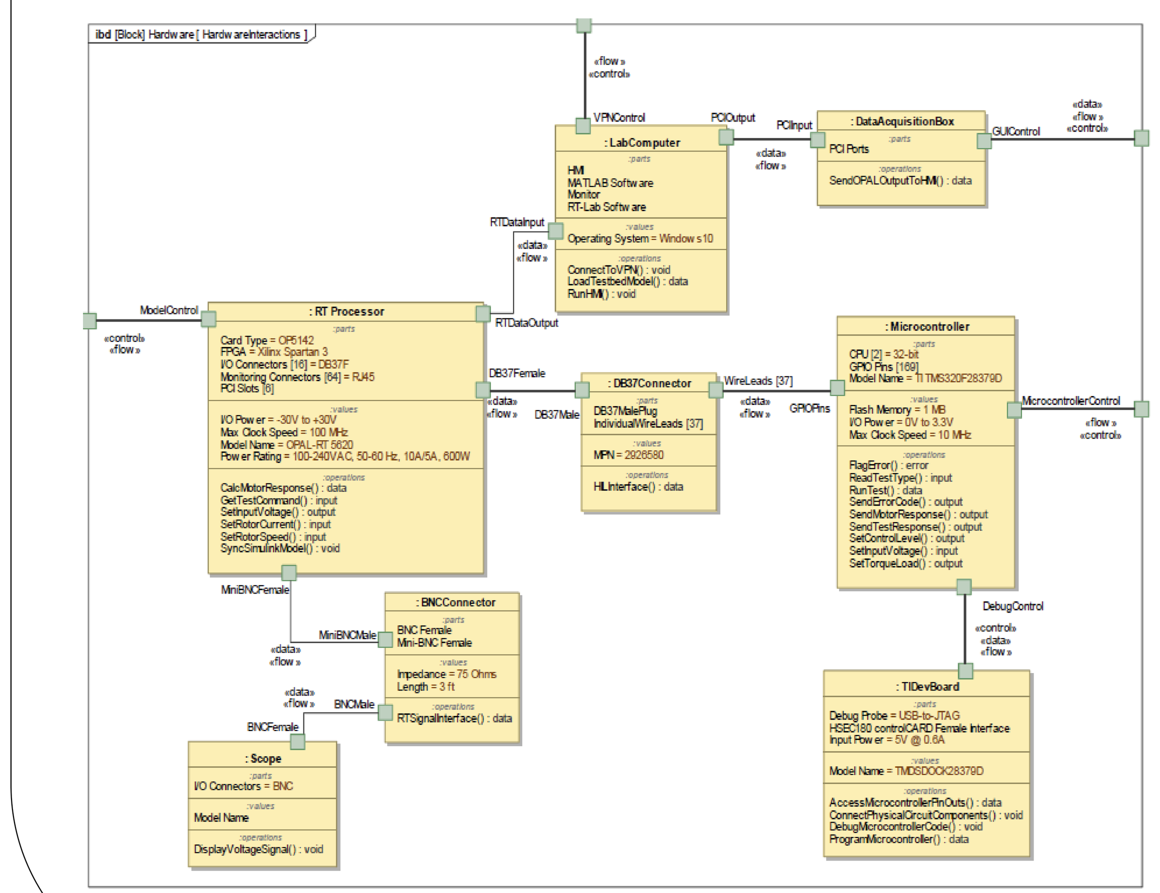
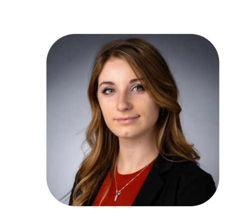


Fig. 7 – Physical Hardware Interface Diagram

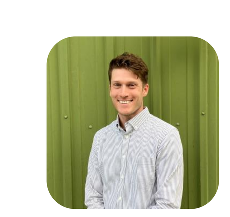
Documentation

- HTML Export of Code Commentary
- TI-OPAL Interface Definition
- Systems Cameo Model
- System Pinout Schematic
- Public GitHub Repository
- Team Website

Team



Kori Eliaz
B.S. Electrical Engineering
Aerospace Concentration
Team Role: Project Manager



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