Energy Management System for Electric Engines Using Collaborative DSP Controllers (EMSEECDC)

Senior Project Proposal

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Project Summary

Engine, temperature, and energy management control system designs will be applied to a small scale electric engine cooling system. Precision control of temperature and fast response to engine power dissipation changes will be achieved by methods such as state-feedback control, observer design, and neural networks. Power dissipation data and temperature data will be exchanged via a Controller Area Network (CAN bus) interface between the engine DSP controller and the thermal DSP controller. The advanced controller methods and communication data channel will allow for better energy management of the system.

Project Goals

Engine Control

1. Employ auto-code generation and real-time control for the Simulink/DSP interface using MATLAB and Code Composer.
2. Understand DSP/motor hardware interface developed from the 08/09 Senior Project.
3. Develop software for PWM and velocity calculations from a rotary encoder using quadrature encoding for improved resolution.
4. Design closed-loop controllers for velocity control. Advanced control techniques will be implemented such as estimating motor current with observer design, state-feedback control, and neural networks.
5. Evaluate controller performance in terms of system accuracy, speed, and energy consumption with and without an external load.
6. Design Simulink/MATLAB GUI for user interface.
7. Design energy management software to limit engine power output based on Thermal DSP data via CAN bus interface.
8. Provide engine data to Thermal DSP via CAN bus.

Thermal Control

1. Understand DSP/cooling system hardware interface.
2. Obtain a mathematical model (transfer function) of the cooling system at different operating temperatures.
3. Design closed-loop controllers for temperature regulation of cooling system and energy management software for control of pump/fan.
4. Provide temperature data to Engine DSP via CAN BUS interface.
5. Determine when the pump and fan should be used and by how much to maximize cooling efficiency.

Project Description

The energy management system consists of five subsystems: a motor-generator system, a liquid cooling system, two fixed-point 32-bit TMS320F2812 DSP control boards, and interface electronics (shown in Figure 1). One DSP control board will be used for engine speed control, while the other DSP control board will be used to regulate engine temperature. A CAN bus interface will be designed to allow communication between the two control systems. This feature will allow for the design of an overall control system that uses minimal energy while providing precise temperature regulation with a fast response to system changes such as engine speed and external load. Advanced control algorithms such as state-feedback control as well as artificial neural networks will be used to estimate engine power.

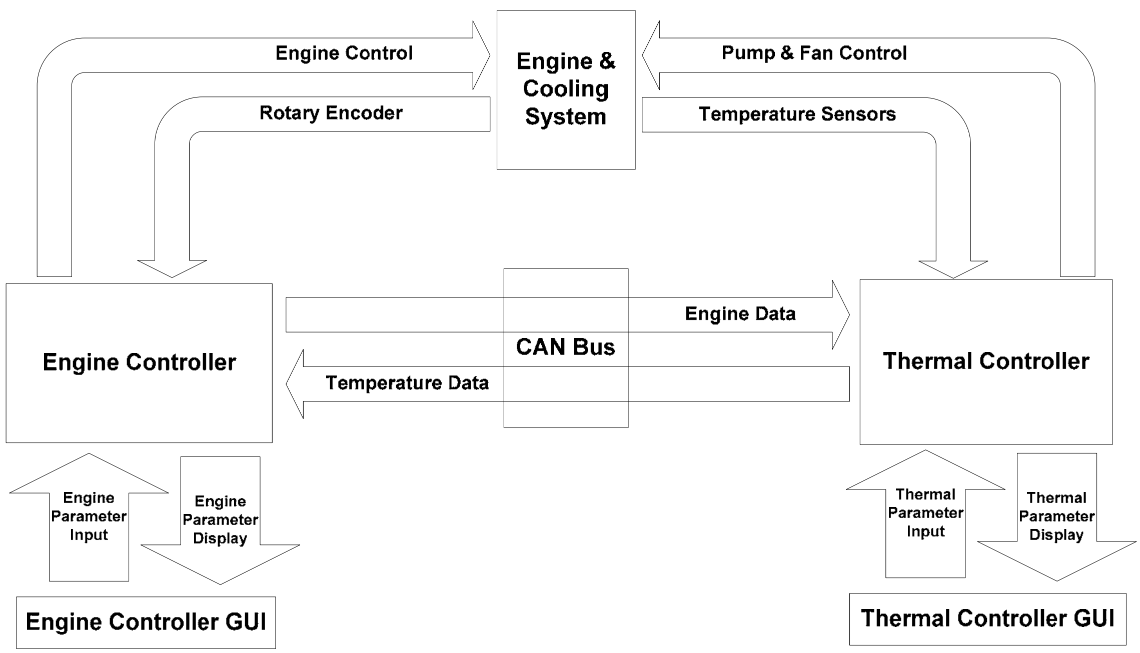

Figure 1 - Overall System Diagram

Engine & Cooling System

The system contains two Pittman DC motors and a Koolance PC cooling system (pump, tank, radiator, fan, cooling block, flow meter, and multiple temperature sensors). These components simulate an electric engine and cooling system of an electric car (shown in Figure 2 & 3).

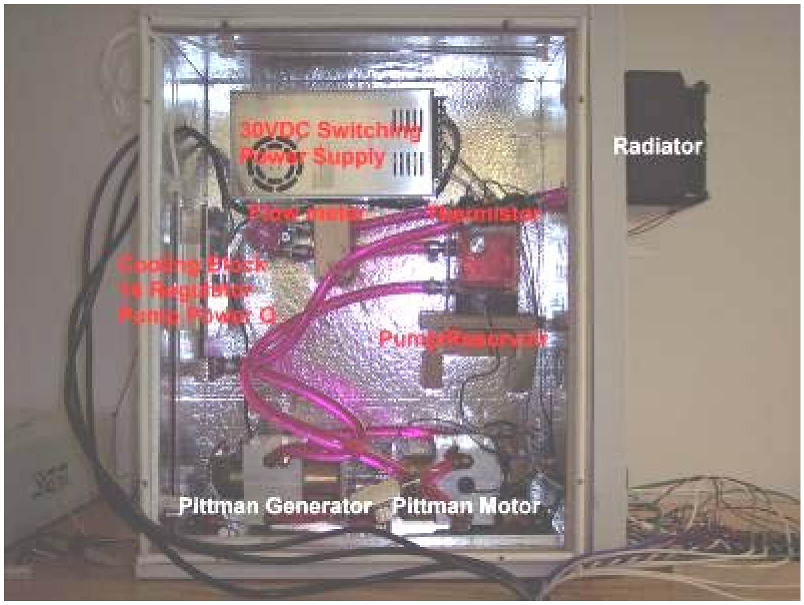

Figure 2 - Engine & Cooling System [2]

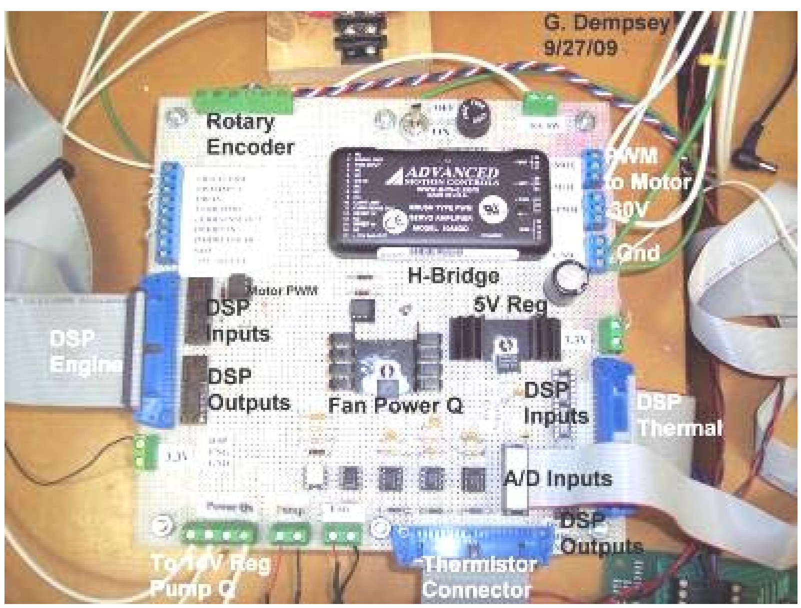

Figure 3 - Thermal & Engine Controller [2]

Thermal Controller & Engine Controller

The thermal controller will receive data from temperature sensors and the CAN Bus to regulate temperature of the cooling system. The engine controller will receive data from the rotary encoder and the CAN Bus to control the engine (shown in Figure 4 & 5).

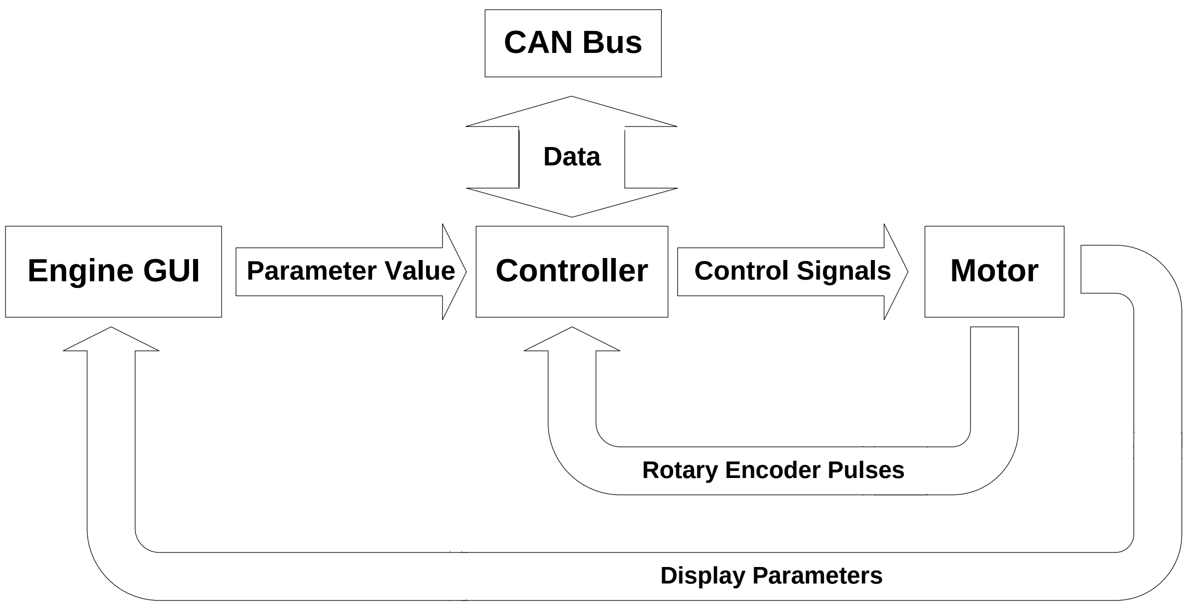

Figure 4 - Engine Controller

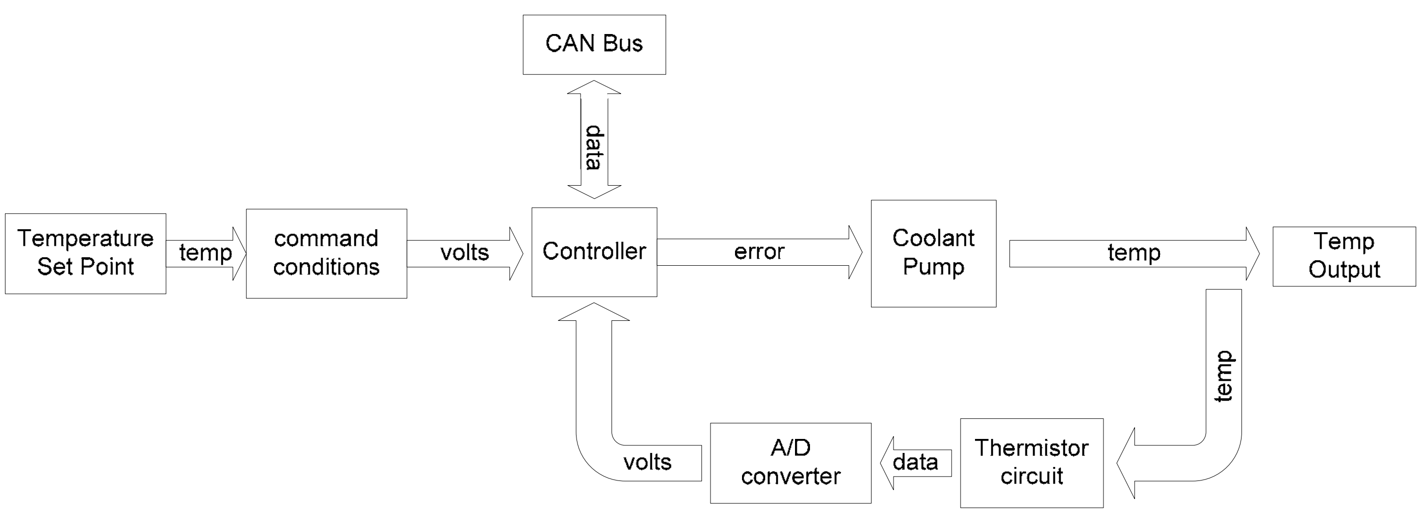

Figure 5 - Thermal Controller

CAN Bus

The CAN Bus is crucial to the energy management of the motor. Power data and Thermal data will be passed between the two DSP boards.

Table 1 - Engine Controller GUI

Input	**Output**
Command Velocity	Velocity
Controller Parameters	Motor Current
	Steady State Error
	PWM %
	Transient Response Plot
	Motor Power Dissipation

Table 2 - Thermal Controller GUI

Input	**Output**
Set Point Temp	Radiator Inlet /Outlet Temp
	Engine Block Temp
	PWM% Fan
	PWM% Pump
	Energy Consumption

Task Schedule

Table 3 - Schedule

Week	**Jacob Teague (Engine Control)**	**James Kirchhoff (Thermal Control)**
1	Finalize Observer Design	Thermal Transfer Function
2	Finalize Observer Design	Thermal Transfer Function
3	CAN Bus & Engine Governor	CAN Bus
4	CAN Bus & Engine Governor	Single-Loop Controller
5	Advanced Controller Design	Single-Loop Controller
6	Advanced Controller Design	Advanced Controller Design
7	Back Propagation ANN	Advanced Controller Design
8	Back Propagation ANN	Energy Management
9	Back Propagation ANN	Energy Management
10	GUI Design	GUI Design
11	Fine Tune Controllers	Fine Tune Controllers
12	Final Report & Presentation	Final Report & Presentation
13	Final Report & Presentation	Final Report & Presentation
14	Final Report & Presentation	Final Report & Presentation

Preliminary Work

Engine Control

During the EE 450 Mini Project a model of the plant (DC Motor) was developed for an engine control system (shown in Appendix A – Figure 1). This model was modified in this project to create a state space model (shown in Appendix A – Figure 2) for the plant that calculates both velocity and current. The value of this internal armature current allows for an instantaneous calculation of power dissipation by taking the armature current squared multiplied by the armature resistance. The continuous time domain state equations derived from this model were put in matrix form (shown in Appendix A – Figure 3) and the determinant of the (SI-A) matrix yielded the location of the closed loop poles at -145.621 and -777.05. An observer design was created to place the desired closed poles at least four to six times the original closed loop poles, at -873.726 and -4662.3, to compensate for Coulomb friction and external motor load (shown in Appendix A – Figure 4 and 5).

Once these values were calculated and implemented the steady state error was 34.8%. Using observer gains L1 and L2 to adjust the closed loop poles to -100 and -20000, the steady state error was reduced to 3.31%. Once the continuous time domain was complete the observer design was used again for discrete time where the poles were placed at 0.0122 and 0.8971. The steady state error obtained from the tuned discrete time observer was 2.2% from the continuous time domain results. Both the Observer Design and the Overall Engine Controller are shown in Appendix A – Figures 6 and 7 respectively.

Thermal Control

The first objective was to determine an equation relating temperature (T) to the resistance of the thermistors (R). The first equation found was

$$R = 291.7088 * e^{-0.027329*T}$$

However, Dr. Dempsey found a website with better equations noted in reference [4]. Next several equations were combined to relate resistance to A/D voltage to A/D output so that the A/D output could be converted into temperature(F). The percentage error is much less in the last equation which is very accurate for the range it will be used. Now that an adequate equation to convert the A/D output to temperature(F) is available, testing of the rise and fall times of the temperature can begin.

Project Specifications

Table 4 - Engine Specs

System	goal
Steady state error	$\pm$5 RPM
Ts	30ms
Tp	20ms
% overshoot	10%
Phase Margin	60^o
Gain Margin	6dB
RPM Range	0 to 834 RPM
Maximum steady state velocity of motor at 750RPM	In 30ms under no load conditions
Maximum steady state velocity of motor at 750RPM	In 100ms under full conditions

Table 5 - CAN Bus Specs

System	goal
P_D to Thermal System	Every 250ms
Coolant temp to engine system	250ms for governor control

Table 6 - Thermal Specs

System	Goal
Steady state error	$\pm$2^{o}F
Ts	10 seconds
Max coolant temp	110^{o}F
% overshoot	10%
Phase Margin	40^o
Gain Margin	6dB
Coolant temp setpoint	100^{o}F
Coolant exceeds 100^{o}F	Limit Power Dissipation through CAN Bus
Rated engine load at 800RPM	Setpoint 100^{o}F

References

[1] Dr. Gary Dempsey. “Energy Management System for Senior Capstone Project 2009/2010,” Bradley University, 2009.

[2] Mark Bright, Mike Donaldson, and Dr. Gary Dempsey. “Engine Control Workstation Using Simulink / DSP Platform: Functional Description and System Block Diagram,” Bradley University, 2009.

[3] Pittman. “LO-COG DC Motors,” Pittman, 2009.

[4] http://www.efunda.com/designstandards/sensors/thermistors/thermistors_theory.cfm

[5] G. Dempsey, "EE432 Control Theory II Workbook", Electrical and Computer Engineering, Bradley University, January 2009.

Appendix A

Engine Control Lab Results

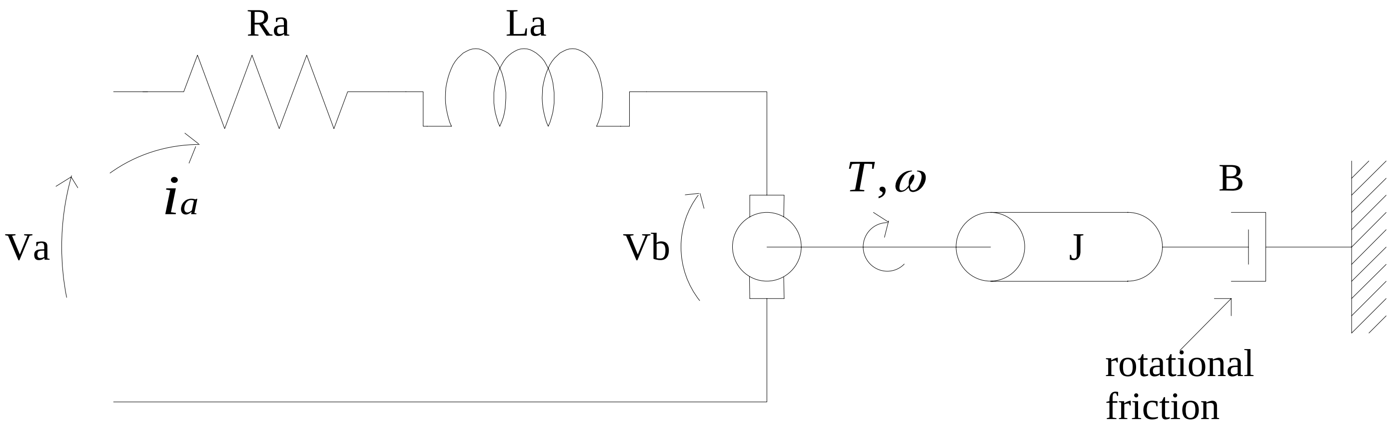

Figure 1 – Motor Circuit [5]

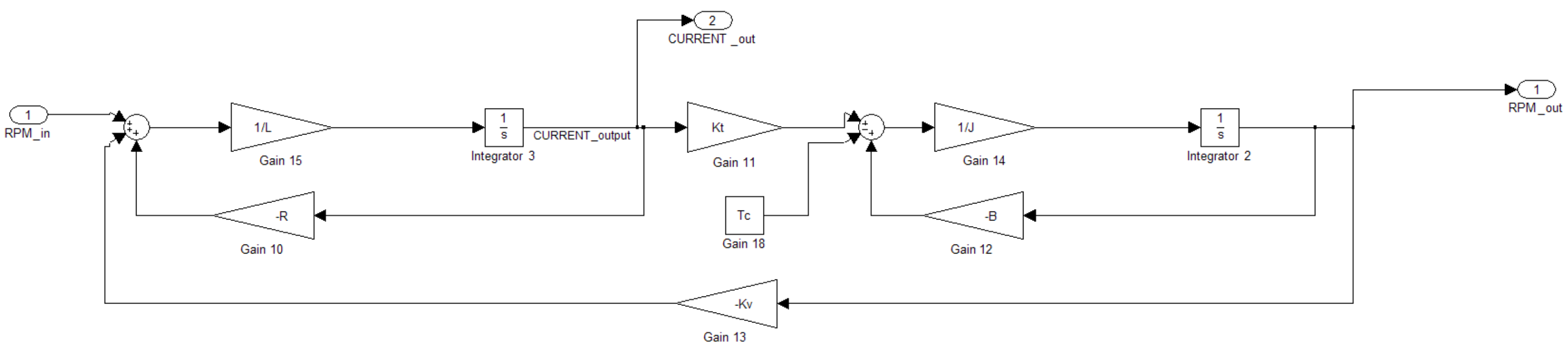

Figure 2 – State-space Motor Block Diagram

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} -B/J & Kt/J \\ -Kv/La & -Ra/La \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 0 \\ 1/La \end{bmatrix} u$$

Figure 3 – State-space Motor Equations [5]

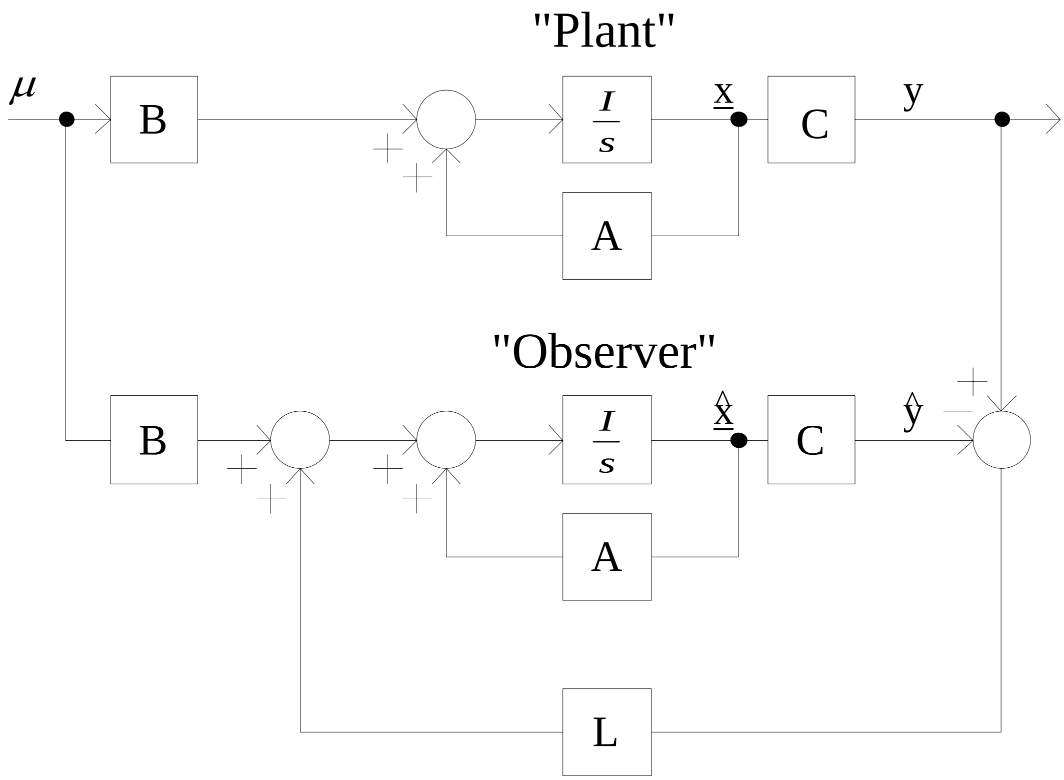

Figure 4– Closed-loop Observer [5]

$$\begin{bmatrix}\dot{\hat{x}}_1\\ \dot{\hat{x}}_2\end{bmatrix} = \left(\begin{bmatrix}-B/J & Kt/J\\ -Kv/La & -Ra/La\end{bmatrix} - \begin{bmatrix}L1\\ L2\end{bmatrix}\begin{bmatrix}1 & 0\end{bmatrix}\right)\begin{bmatrix}\hat{x}_1\\ \hat{x}_2\end{bmatrix} + \begin{bmatrix}0\\ 1/La\end{bmatrix}u + \begin{bmatrix}L1\\ L2\end{bmatrix}\begin{bmatrix}1 & 0\end{bmatrix}\begin{bmatrix}x_1\\ x_2\end{bmatrix}$$

$$\begin{bmatrix}\dot{\hat{x}}_1\\ \dot{\hat{x}}_2\end{bmatrix} = \left(\begin{bmatrix}\begin{bmatrix}-B/J-L1 & Kt/J\\ -Kv/La-L2 & -Ra/La\end{bmatrix}\end{bmatrix}\right)\begin{bmatrix}\hat{x}_1\\ \hat{x}_2\end{bmatrix} + \begin{bmatrix}0\\ 1/La\end{bmatrix}u + \begin{bmatrix}L1 & 0\\ L2 & 0\end{bmatrix}\begin{bmatrix}x_1\\ x_2\end{bmatrix}$$

Figure 5 – Closed-loop Observer Equations [5]

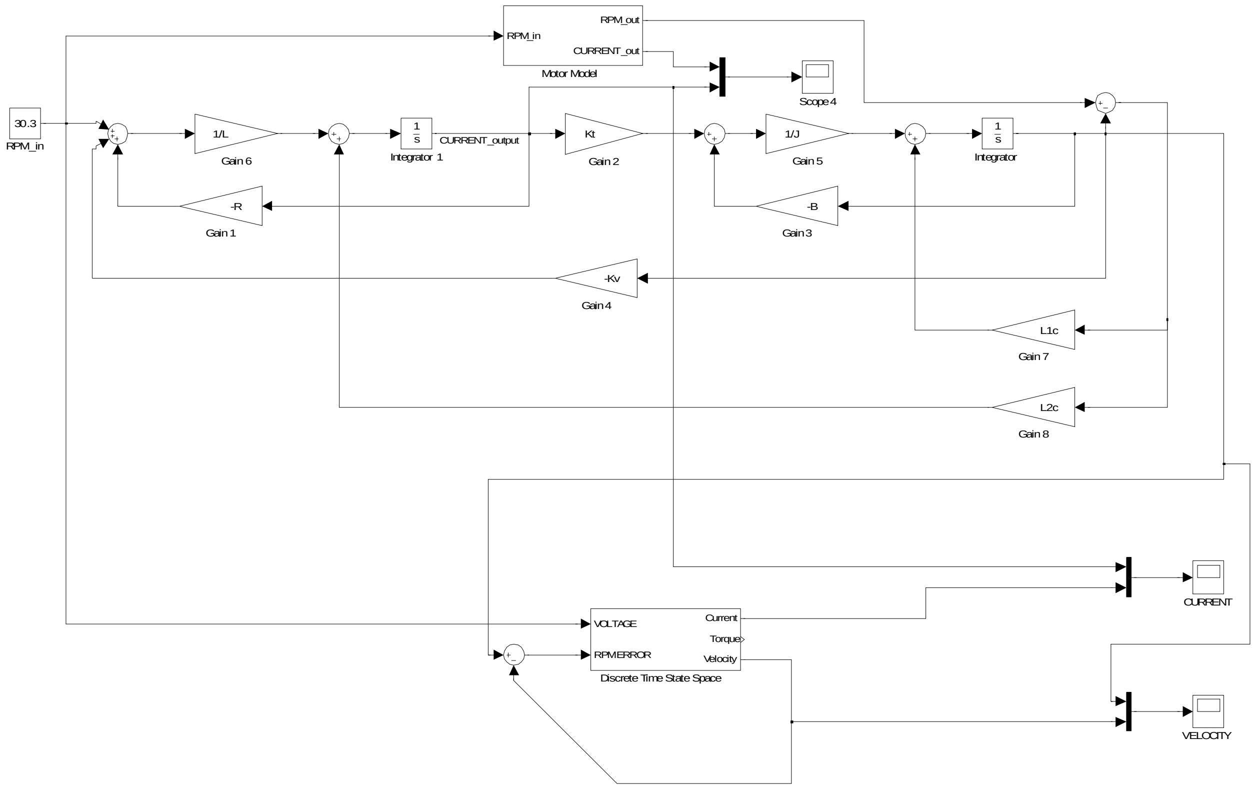

Figure 6 – Observer Design

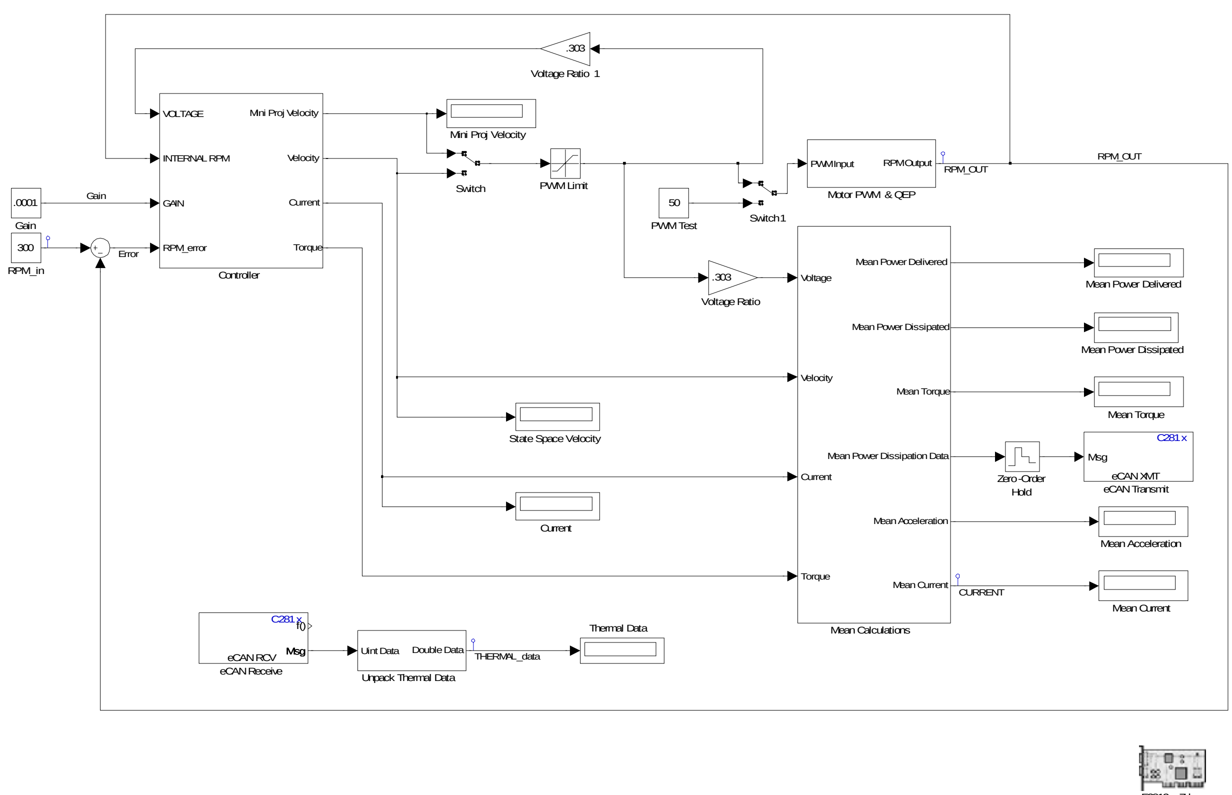

Figure 7 – Overall Engine Controller

Appendix B

Thermal Control Lab Results

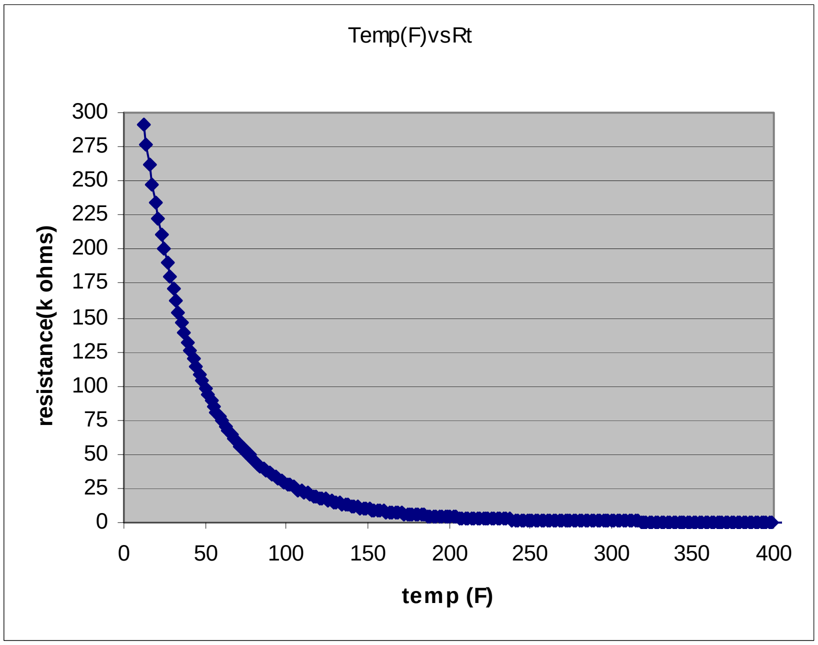

Figure 1 – Temperature(F) vs Resistance (Kohms)

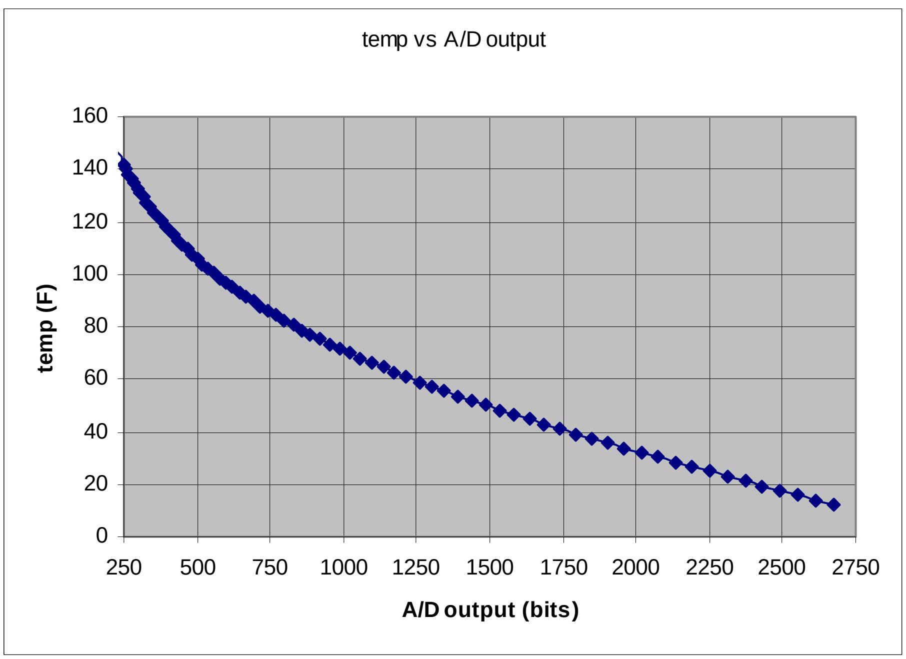

Figure 2 – A/D output vs Temperature(F)

$$\frac{1}{T} = \frac{1}{T_{\mathrm{Ref}}} + \frac{1}{\beta}[\ln(R) - \ln(R_{\mathrm{Ref}})]$$

$$T = \frac{T_{\mathrm{Ref}} + \beta}{\beta + T_{\mathrm{Ref}}[\ln(R) - \ln(R_{\mathrm{Ref}})]}$$

Figure 3 – Temperature(K) Equations from reference [4]

$$temp(F) = \left(\left[\frac{1183655.5}{298.15 * \ln\left[\frac{200 * A/D\_output}{221315.072 - 49.12 * A/D\_output}\right]}\right] - 273.15\right) * 9/5 + 32$$

Figure 4 – Equation converting A/D output into Temperature (F)

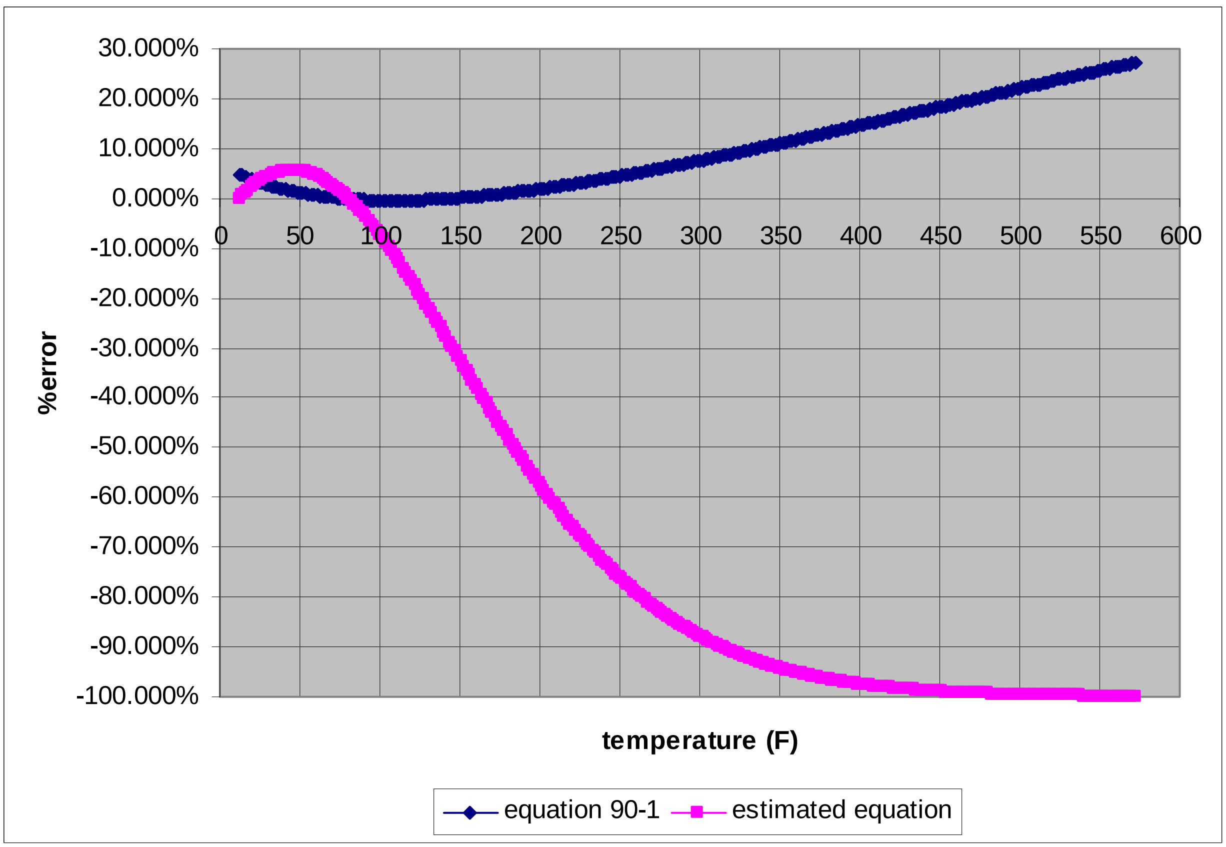

Figure 5 – Percentage Error of Estimated Equations vs Equations from Reference [4] along Temperature (F)

Time from start of experiment	estimated temperature	status of motor
Start	71°F	full speed, no load
1 hour 45 min	84°F	stopped at this time
2 hours 5 min	81°F	stopped
3 hours 10 min	75°F	stopped
5 hours 20 min	73.25°F	stopped
6 hours 40 min	73.5°F	full speed, 88Ω load*
6 hours 55 min	79.1°F	full speed, 44Ω load**
7 hours 25 min	90°F	stopped

*26.5V for generator / 88Ω load = 0.301 A current

**23.9V for generator / 44Ω load = 0.593 A current

Figure 6 – test results of temperature of motor

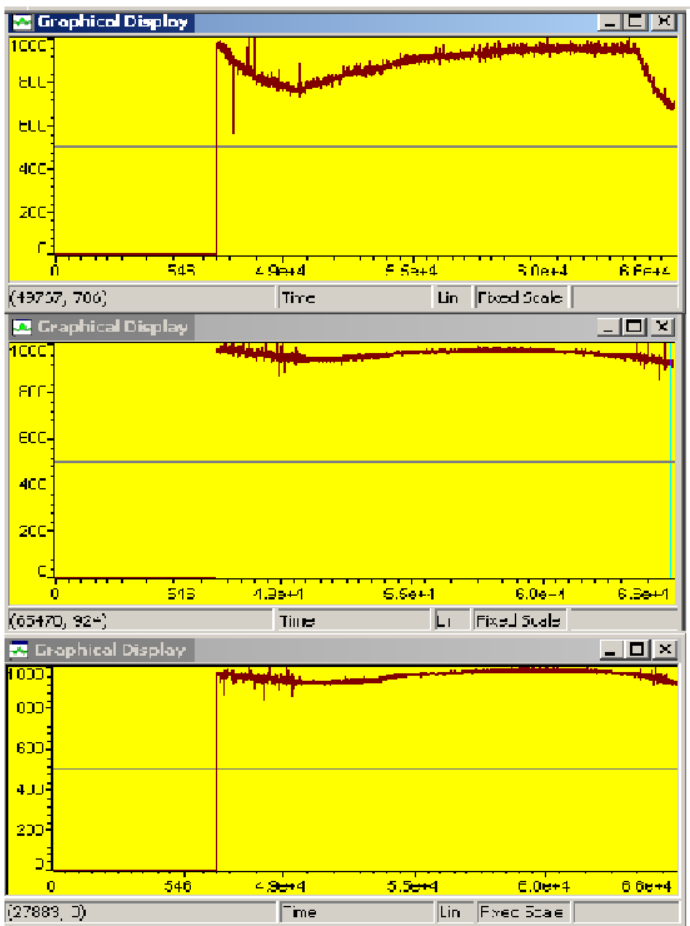

Figure 7 – Graph of Figure 6 and other 2 Thermistors (A/D output vs. time)

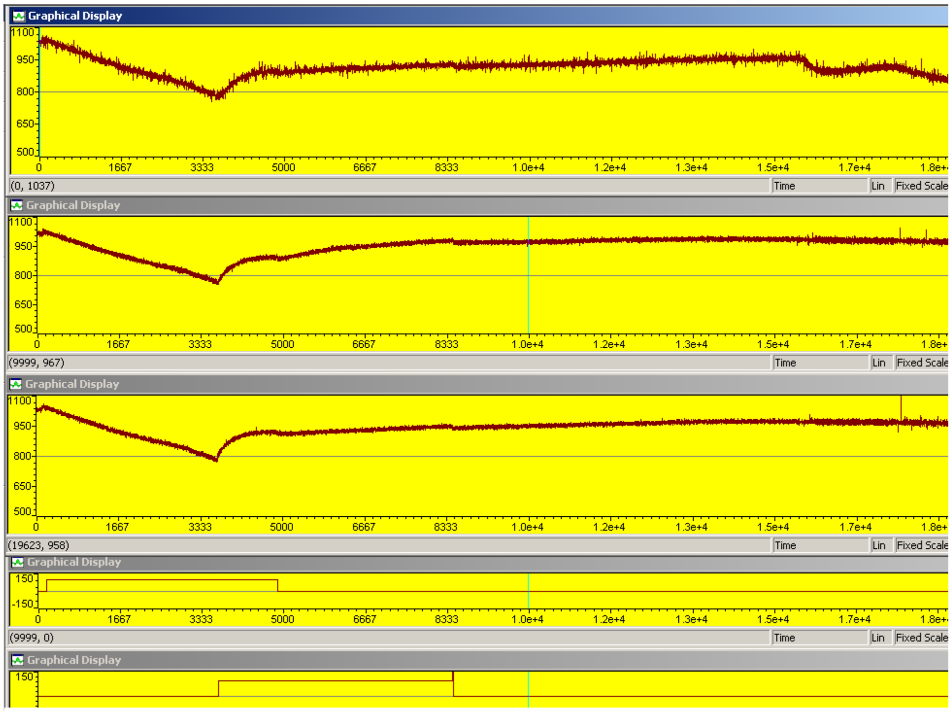

Figure 8 – Temperature (A/D output) Change as Pump and Fan are turned on and off as shown in Graphs