Senior Design: Steam Heat Controller

Team Members: Curtis Mayberry, Ben Cao,
Thinh Luong, Ben Jusufovic

Advisors: Lee Harker, Jason Boyd

Overview

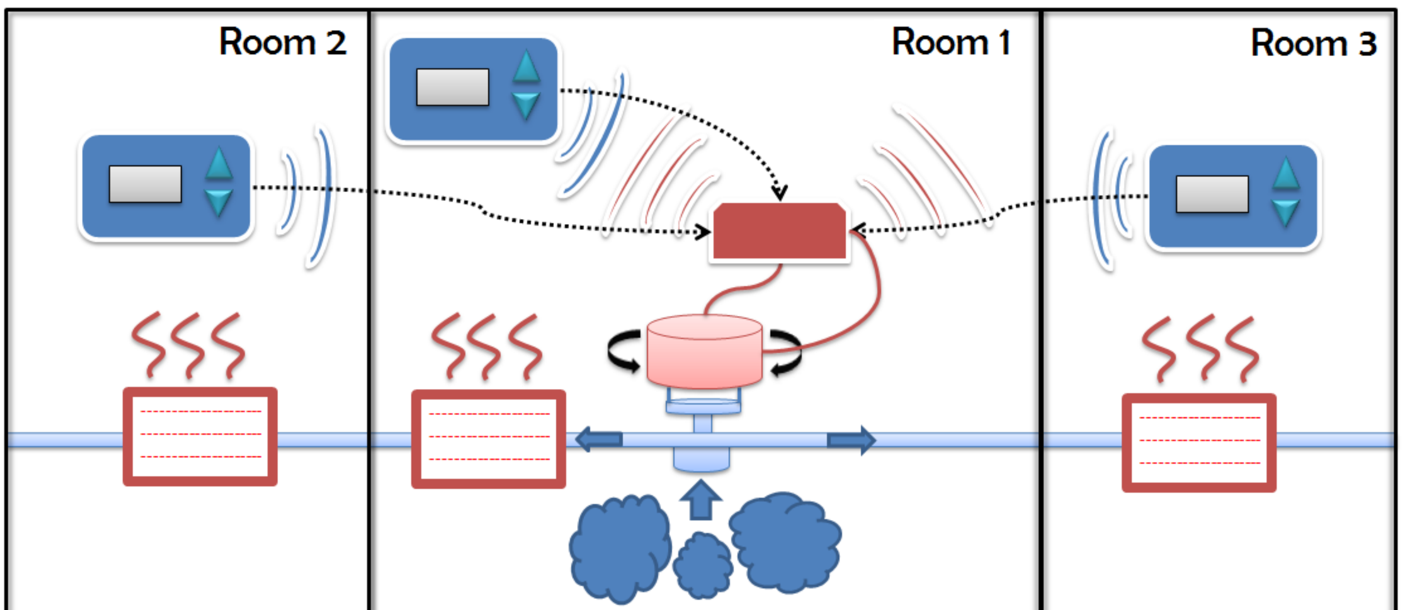
- Project Goals & Concept Diagram
- System Decomposition
- System Design
- Test Plan
- Resources and budget
- Current Status

Problem Statement

Currently, the old section of Coover utilizes steam valves in order to heat adjacent rooms. In extreme cases, one steam valve controls the temperature in five different rooms through five radiators. This leads to temperature offset in the rooms and continuous adjustment of the valve in order to accommodate the individuals within each room.

Project Goal

- The goal of our project is to provide a user interface that will allow individuals to set a desired temperature within multiple rooms without ambiguity and a heat valve controller unit that will accommodate the desired temperature. Our project will also provide remote system access to Facilities Planning and Management in order to save on energy costs and system management.



Functional Requirements

Intended use as a thermostat helps define:

- Effectively control the temperature in the room
- Take occupant's preferences
- Multiple room control
- External control
- Removable mechanical interface
- Network interface

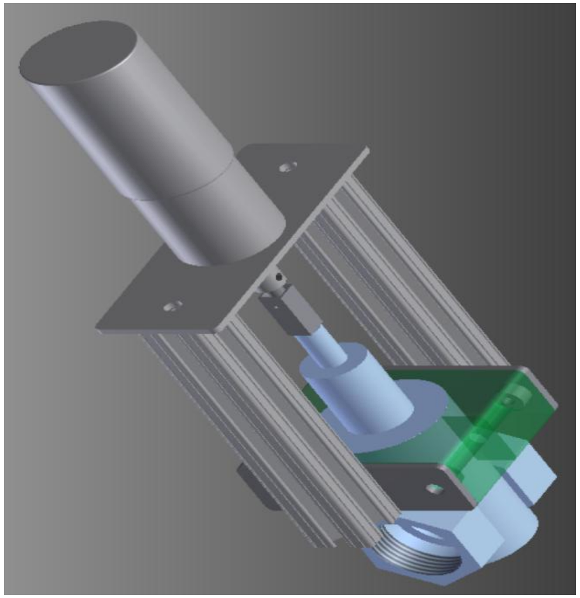
Non-Functional Requirements

Considering the user interface unit:

- Large LCD – visibility
- Graphical based LCD – usability
- Gray, green, yellow, or blue tint of LCD – aesthetic appeal.
- Large rubber base push buttons – usability.
- Translucent push buttons – aesthetic appeal.

Market Research

- Current solutions
  - Automated Valve & Equipment Co.
  - Johnson Controls
- Our solution
  - Minimal modification
  - Adaptable to numerous valves
  - Simple web interface
- Target clients
  - Coover Building
  - Sweeney, Gilman, Physics Hall…



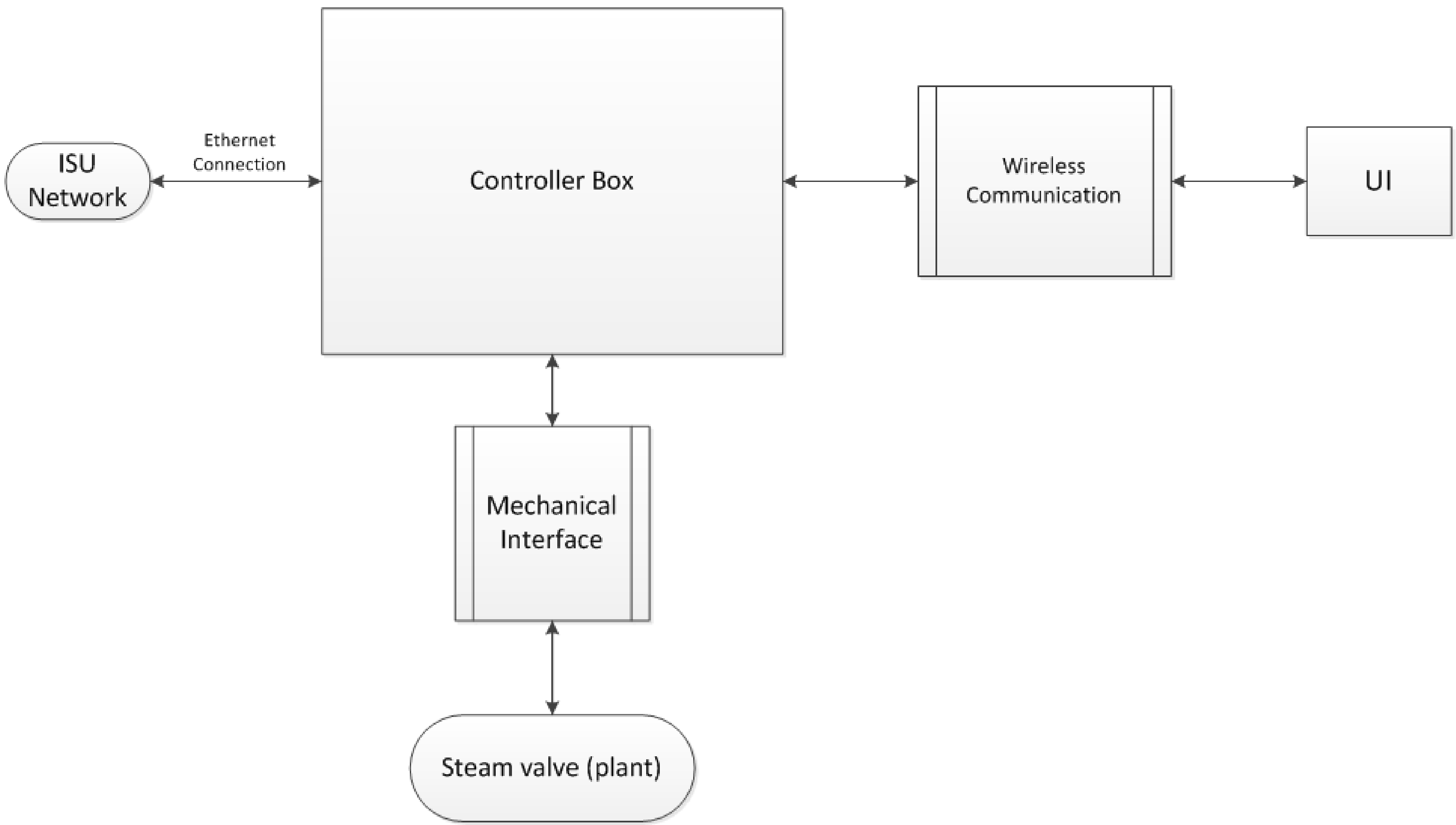
Potential Risks & Mitigation

- Hardware failure
- Mechanical interface integration delays
- Loss of a team member
- Short testing window
- Power Failure
- Component obsolescence
- Unexpected lead times

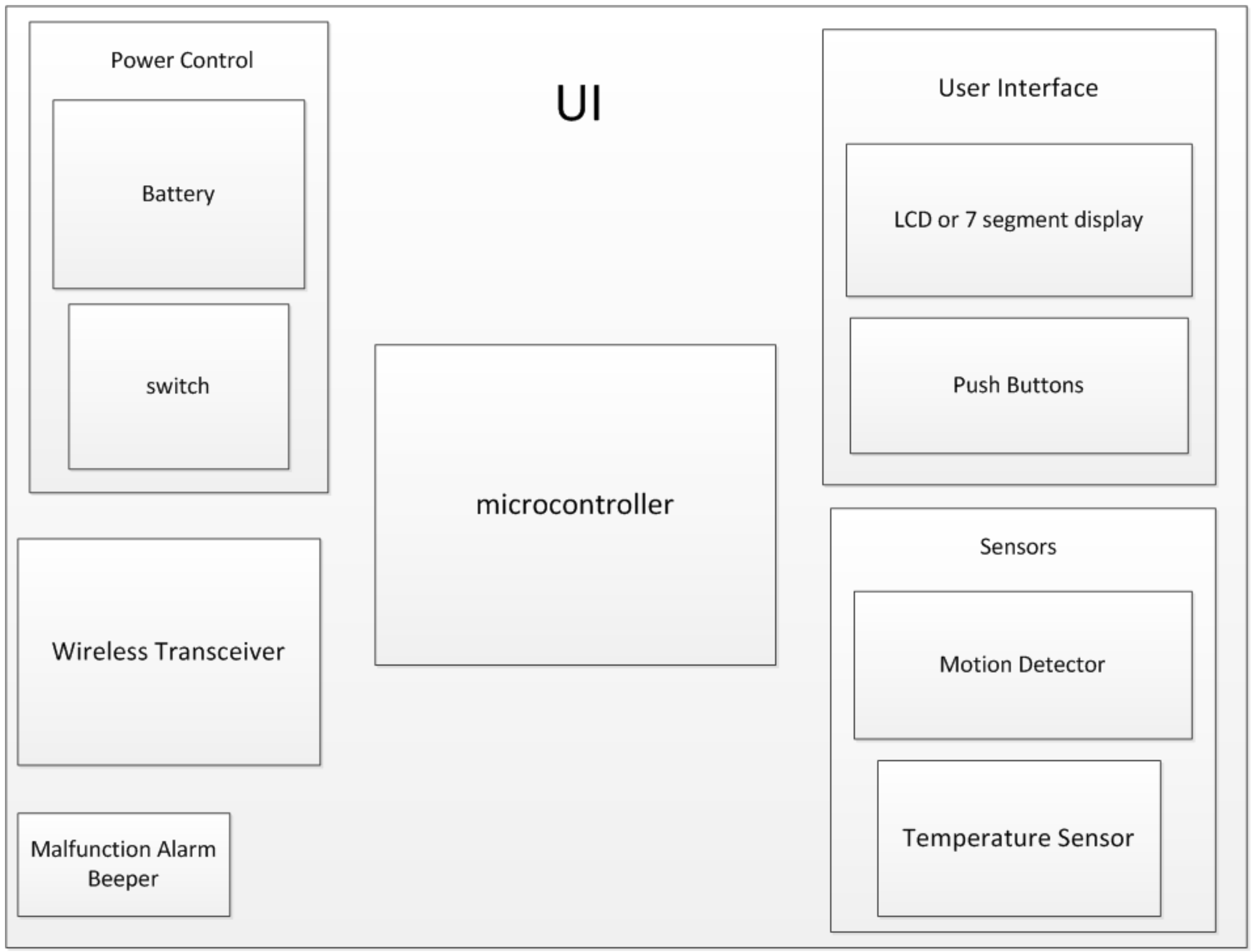
Constraints

- Temperature Sensors controlled by wireless
- Mechanical implementation
- Temperature differentiation between rooms
- Plant restrictions (heat output)
- Minimum alteration to existing infrastructure
- Limited heat output
- User rationality:
- Limited testing period

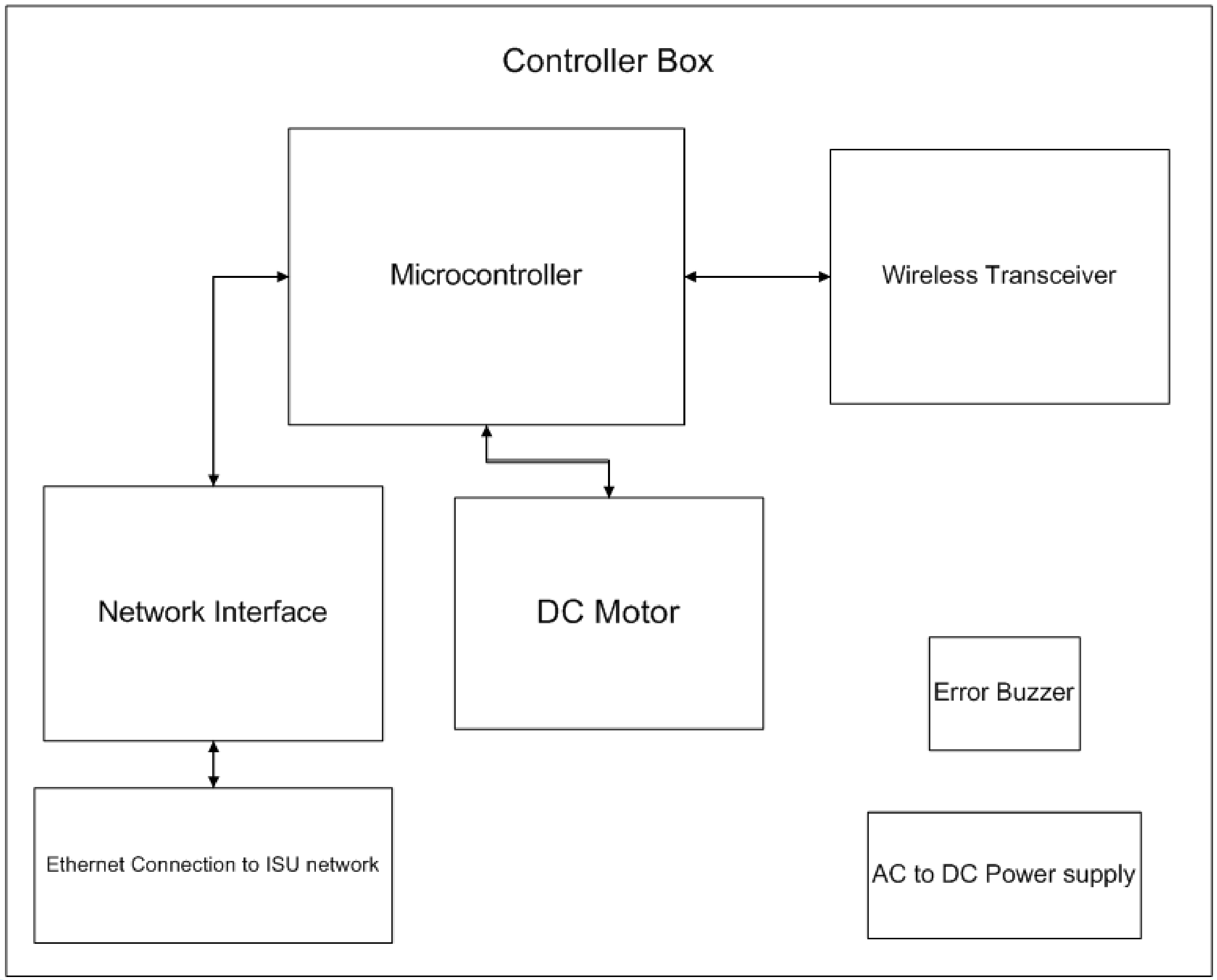
System Decomposition



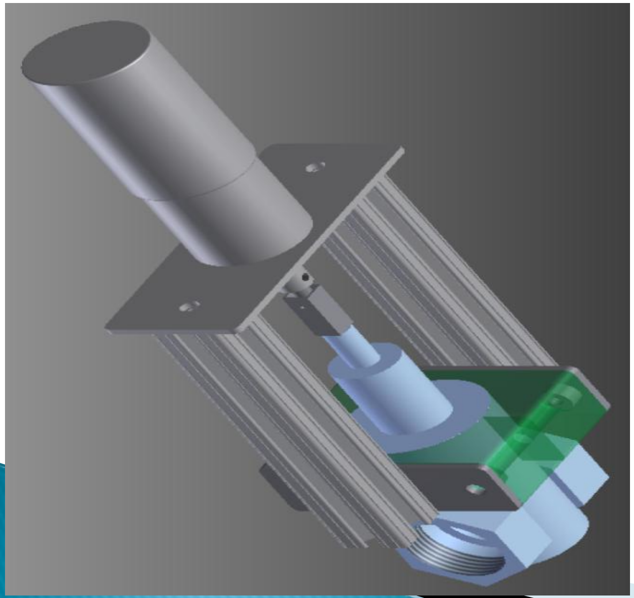
User Interface

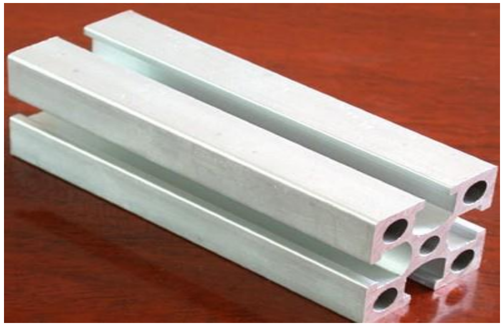


Controller Box



Mechanical Interface



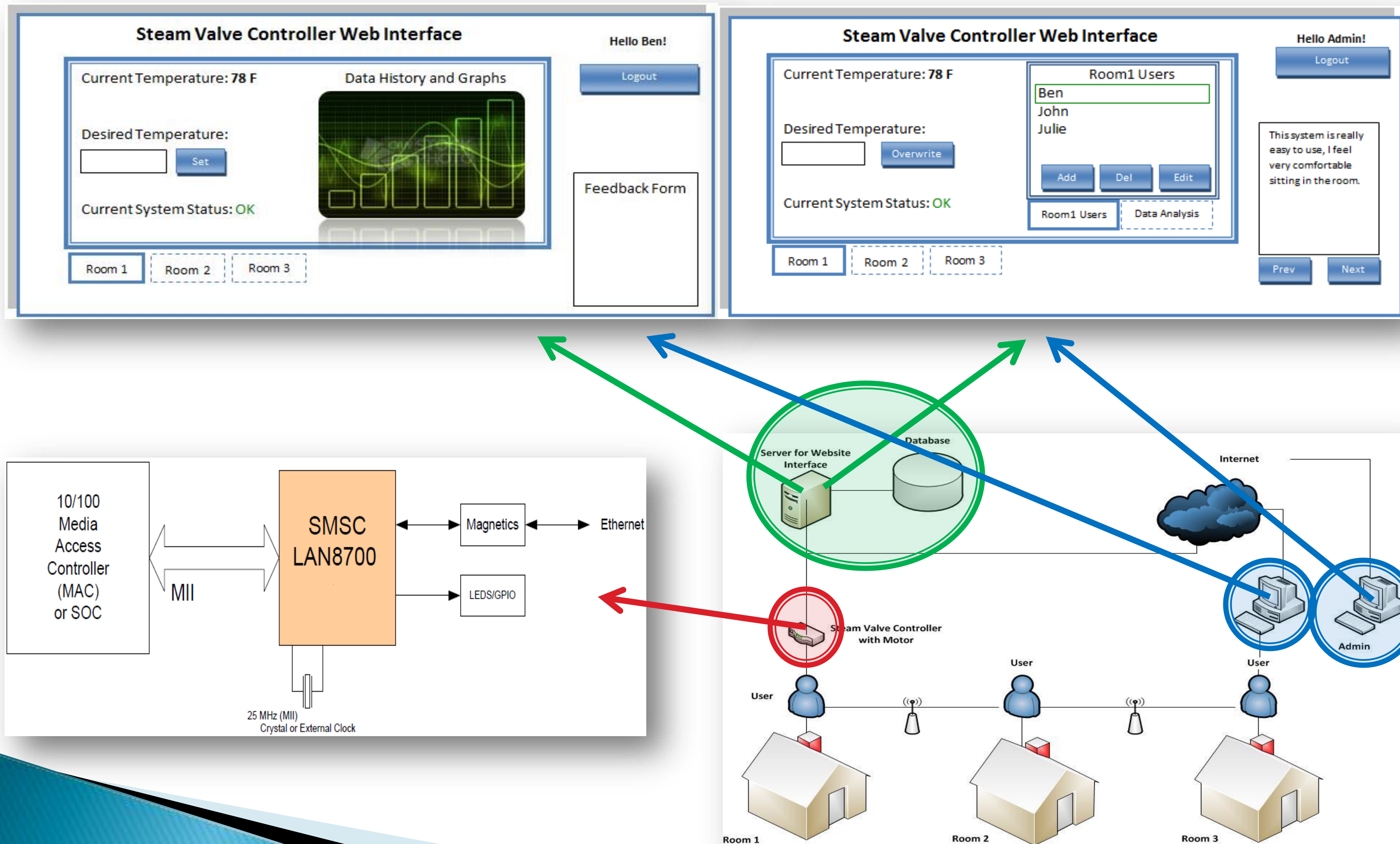


- Extruded Aluminum

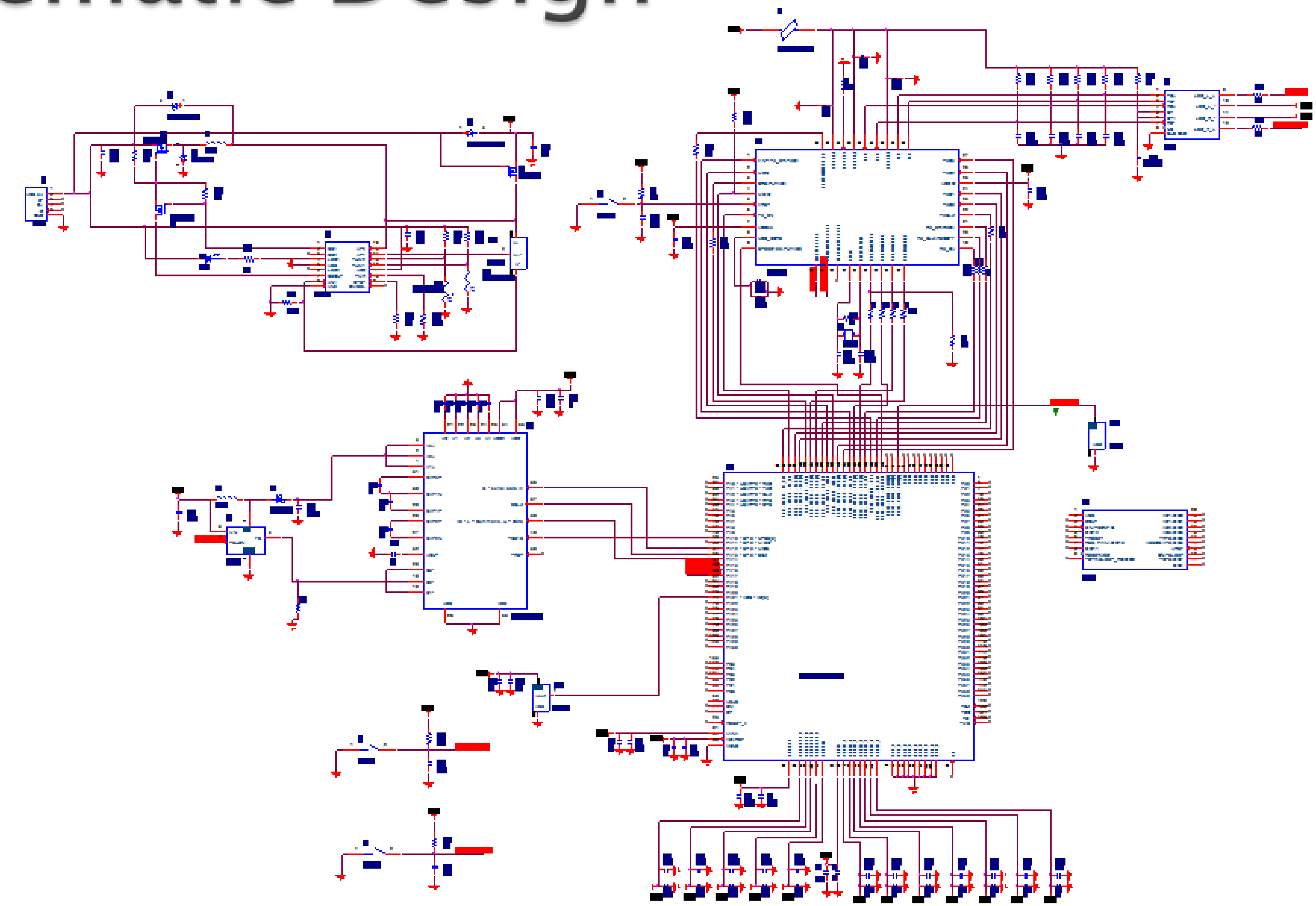
- IG52 Gear motor

- L298N Motor Driver

Ethernet and Web Interface

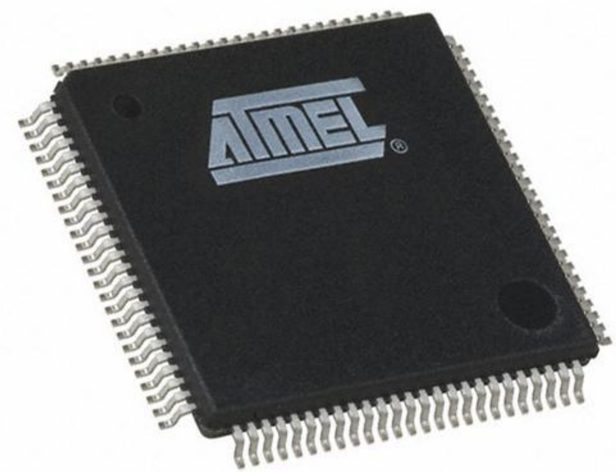


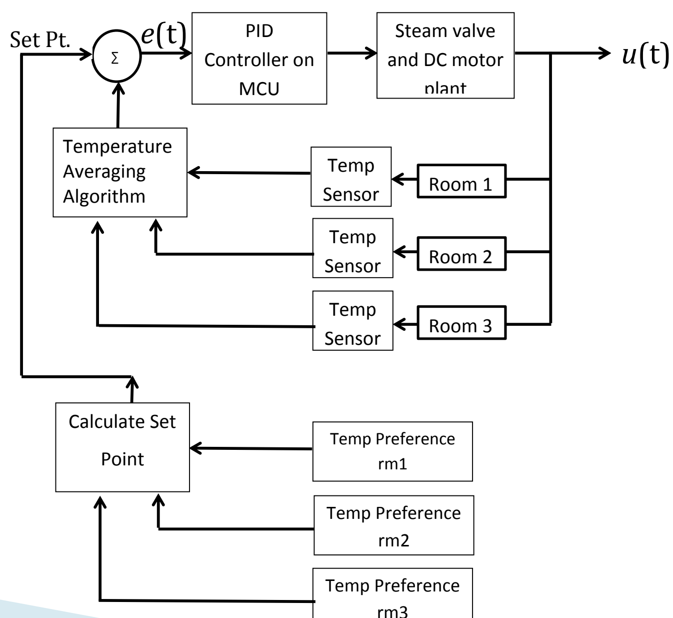
Schematic Design



Wireless Transceiver Controller Algorithm

- Xbee 802.15.4
- Extended range (high power)
- PID controller algorithm
- 32 bit Atmel Microcontroller





Functional Test Plan

- Valve calibration
- Range Test
- Response Test
- Equalization and weighting Test
- Environmental and extreme Tests
- Monitored extended use testing

Software Test Plan

- Component Testing
  - Microcontroller, Temperature Sensor, and LCD
  - Ethernet Components
  - Wireless transceiver
  - Website Interface
- Comprehensive systems

Hardware Test Plan

- Power
- DC Motor
- Microprocessor
- LCD
- Unit casings
- Temperature sensor
- Push Buttons

Resource/Cost Estimate

Estimated Project Costs					
MODULE	ITEM DESCRIPTION	VENDOR	COUNT	PRICE/UNIT	PRICE
Controller panel		various	3	$ 115.83	$ 347.49
Controller box		various	1	$ 208.04	$ 208.04
Microcontroller development kit		Atmel	1	$ 265.00	$ 265.00
Xbee development supplies		various	2	$ 25.00	$ 50.00
Subtotal					$ 870.53
LABOR COST			HOURS	PAY/HOUR	PRICE
Ben Jusufovic	Based on $60000 /year estimate from Career Services		200	$ 28.84	$ 5,768.00
Ben Cao			200	$ 28.84	$ 5,768.00
Curtis Mayberry			200	$ 28.84	$ 5,768.00
Thinh Luong			200	$ 28.84	$ 5,768.00
Subtotal					$ 23,072.00
TOTAL					**$ 23,942.53**

Project Milestones and Current Status

	Start	End	% Compl.
Problem Definition	8/30	9/7	
Problem Definition Completion	8/30	9/3	100%
End-User(s) and End-Use(s) Identification	9/2	9/7	100%
Constraint Identification	9/2	9/7	100%
Technology Considerations and Selection	9/9	10/8	
Identification of Possible Technologies	9/9	9/15	100%
Identification of Selection Criteria	9/15	9/21	100%
Technology Research	9/21	9/29	100%
Technology Selection	9/30	10/8	100%
End-Product Design	9/24	12/31	
Identification of Design Requirements	9/24	10/4	100%
Documentation of Design	10/22	12/6	100%
Design Process	10/4	12/31	60%
Project Reporting			
Project Plan Development	9/14	10/11	100%
End-Product Design Report Development	11/22	12/7	100%

Future Project Milestones and Status

	Start	End	% Compl.
End-Product Prototype Implementation	11/5	2/21	
Identification of Prototype Limitations and Substitutions	1/1	2/14	10%
Implementation of Prototype End Product	1/1	2/21	0%
End-Product Testing	12/24	4/4	
Test Planning	12/24	1/10	0%
Test Development	2/15	2/21	0%
Test Execution	2/22	3/20	0%
Test Evaluation	3/20	4/2	0%
Documentation of Testing	3/21	4/4	0%
End-Product Documentation	1/1	4/17	
Development of End-User Documentation	2/14	3/14	0%
Development of Maintenance and Support Documentation	1/1	4/17	0%
End-Product Demonstration	3/1	4/11	
Demonstration Planning	3/1	3/14	0%
Faculty Advisor(s) Demonstration	3/15	3/28	0%
Client Demonstration	3/29	4/4	0%
Industrial Review Panel Demonstration	4/5	4/11	0%
Project Reporting	8/24	5/4	
Project Plan Development	9/14	10/11	100%
End-Product Design Report Development	11/22	12/7	100%
Project Poster Development	3/1	4/4	0%
Project Final Report Development	4/5	5/3	0%
Weekly Email Reporting	8/24	5/4	45%

Responsibilities & Contributions

- Curtis Mayberry – Webmaster, wireless transceiver, control algorithms design
- Ben Cao –Team leader, web interface, Ethernet interface
- Ben Jusufovic – Communications liaison, LCD, power system design, schematic design
- Thinh Luong – Systems engineer, mechanical interface, motor implementation
- Even responsibilities and contributions
- Collaborative effort

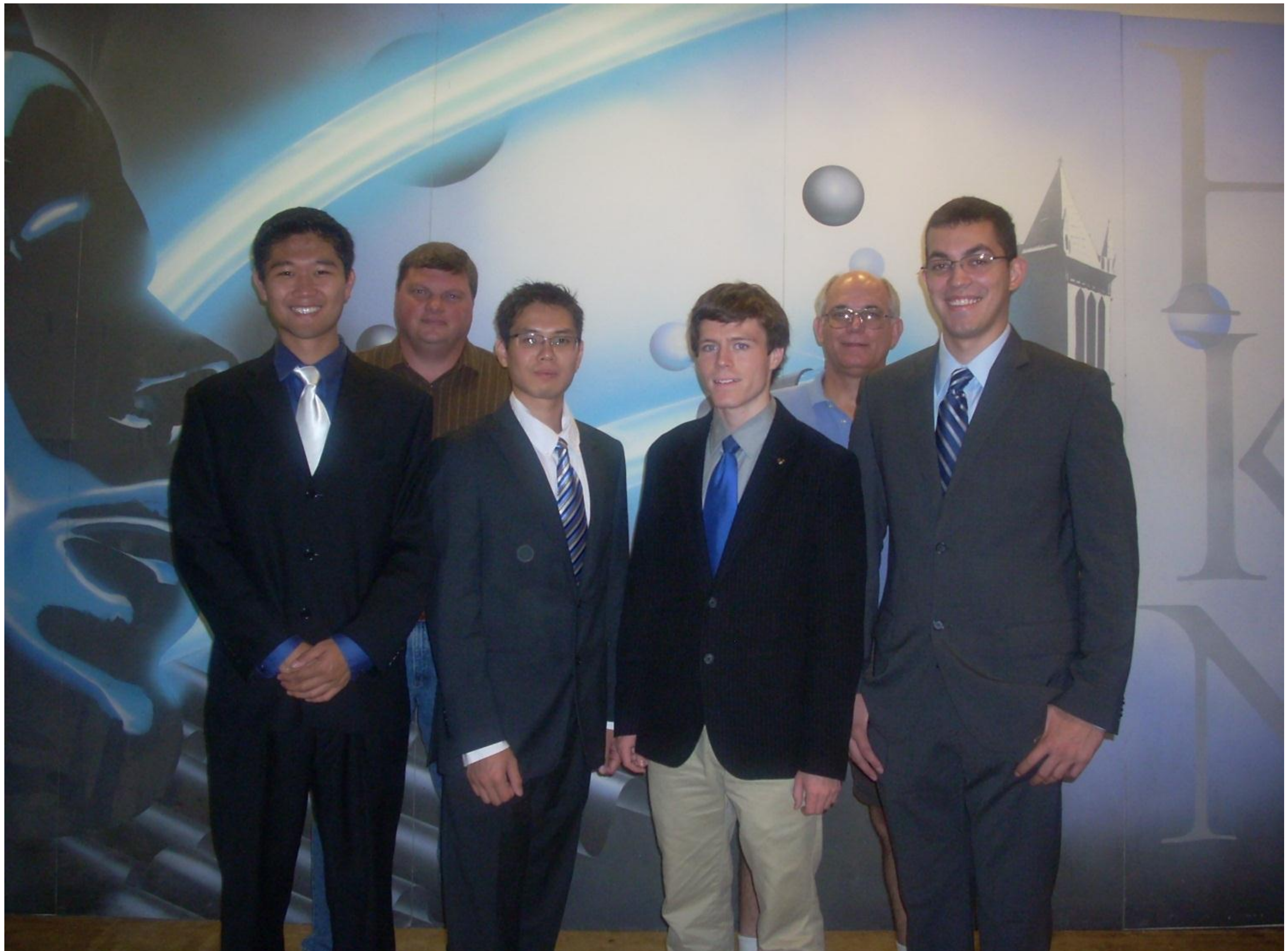
Plan for Winter Break

- Complete PCB design
- Populate PCB
- Implement Microcontroller Peripheral Software
- Attach mechanical platform and implement controller

Plan for Next Semester

- Complete hardware prototype
- Complete network interface
- Tune controller algorithm
- Hardware and software testing
- Functional testing
- End user documentation

Questions?



Appendices

- Encore!

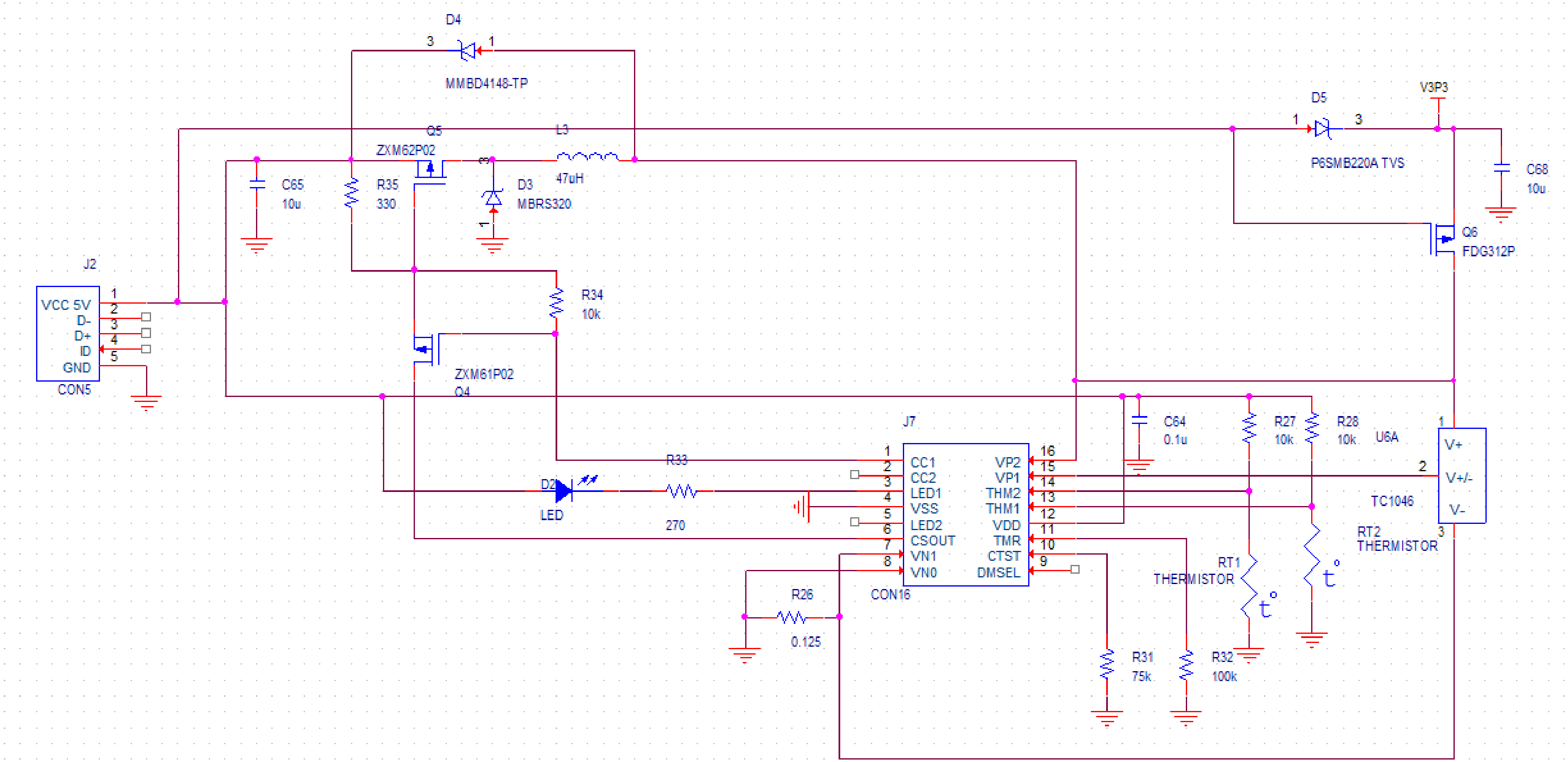
Controller Box Budget

Controller Box					
MODULE	ITEM DESCRIPTION	VENDOR	COUNT	PRICE/UNIT	PRICE
DC motor	IG42 24v gear motor	MPJA	1	$ 59.99	$ 59.99
Motor driver circuit	L298N	Digikey	1	$ 4.78	$ 4.78
Metal platform	Extruded aluminum	80/20	1	$ 15.00	$ 15.00
Tranceiver	Digi Xbee PRO XBee	Digi	1	$ 30.00	$ 30.00
AC to DC power supply			1	$ 60.00	$ 60.00
Miscellaneous components		ECPE	1	$ 8.00	$ 8.00
Microcontroller		Mouser	1	$ 10.00	$ 10.00
Malfunction alarm beeper			1	$ 1.00	$ 1.00
LCD and LCD backlight		Mouser	1	$ 22.00	$ 22.00
Ethernet driver		Mouser	1	$ 2.28	$ 2.28
PCB			1	$ 33.00	$ 33.00
TOTAL					**$ 246.05**

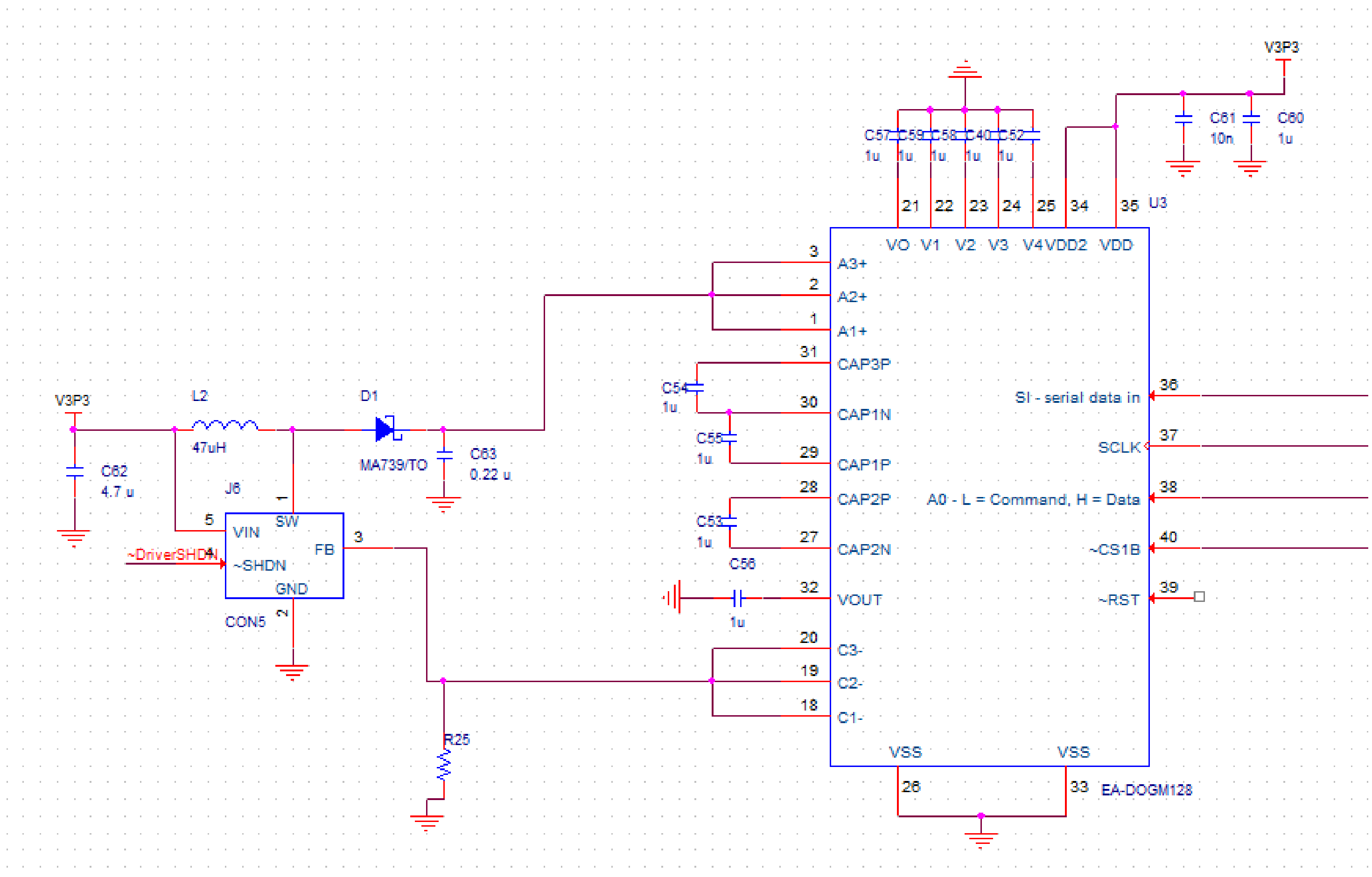
Control Panel (UI)

Control Panel					
MODULE	ITEM DESCRIPTION	VENDOR	COUNT	PRICE/UNIT	PRICE
Temperature sensor	IC TEMP-VOLT CONV PREC SOT23B	Digikey	1	$ 0.70	$ 0.70
LCD and LCD backlight		Mouser	1	$ 22.00	$ 22.00
Transceiver	Digi Zigbee PRO XBee	Digi	1	$ 30.00	$ 30.00
Miscellaneous components		ECPE	1	$ 5.00	$ 5.00
Microcontroller		Mouser	1	$ 20.00	$ 20.00
Malfunction alarm beeper			1	$ 1.00	$ 1.00
Battery	2 rechargeable NiMH AA batteries		1	$ 4.00	$ 4.00
USB battery recharging circuit		Mouser	1	$ 2.58	$ 2.58
PCB			1	$ 33.00	$ 33.00
TOTAL					**$ 118.28**

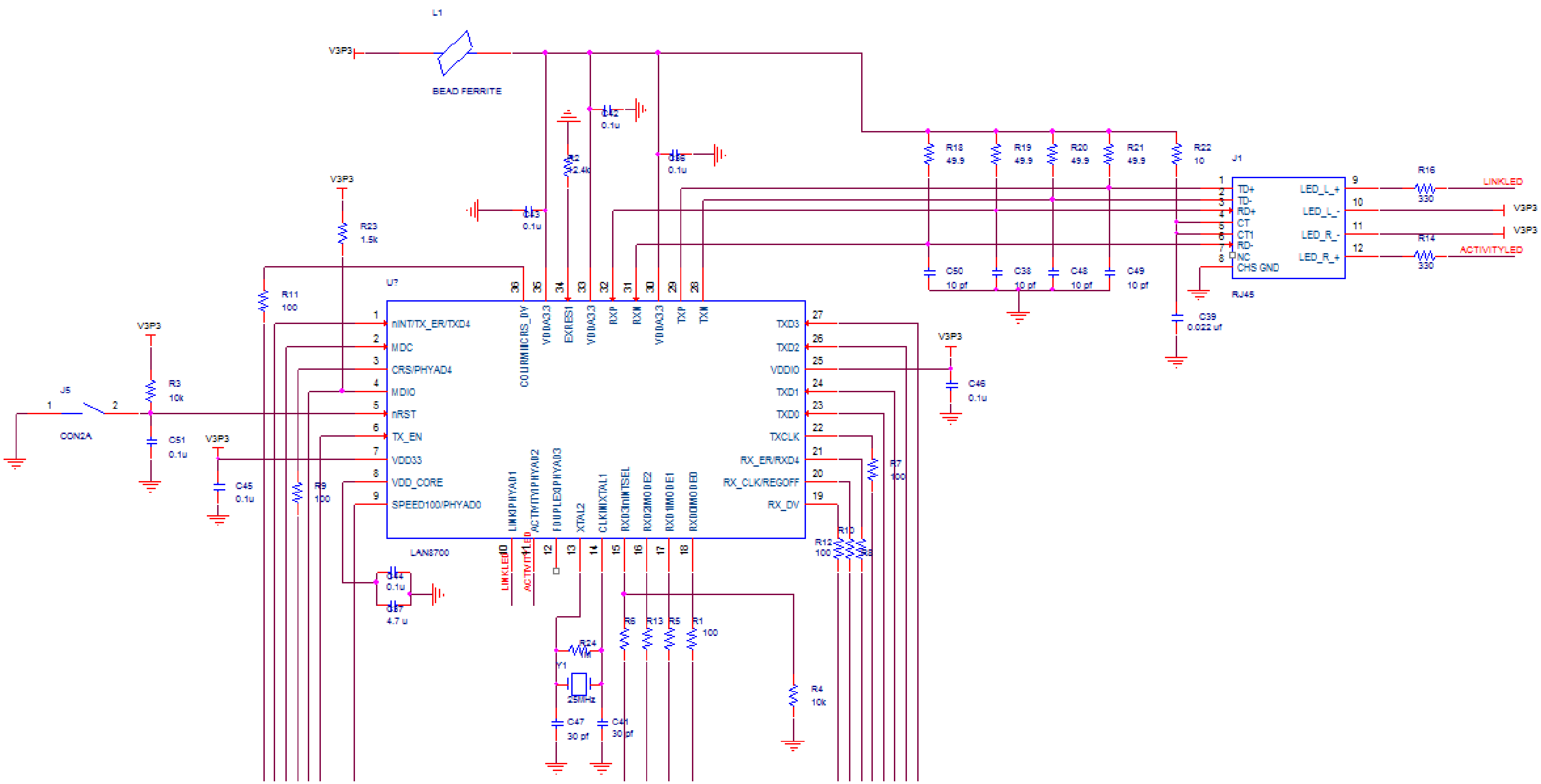
USB Charging Circuitry



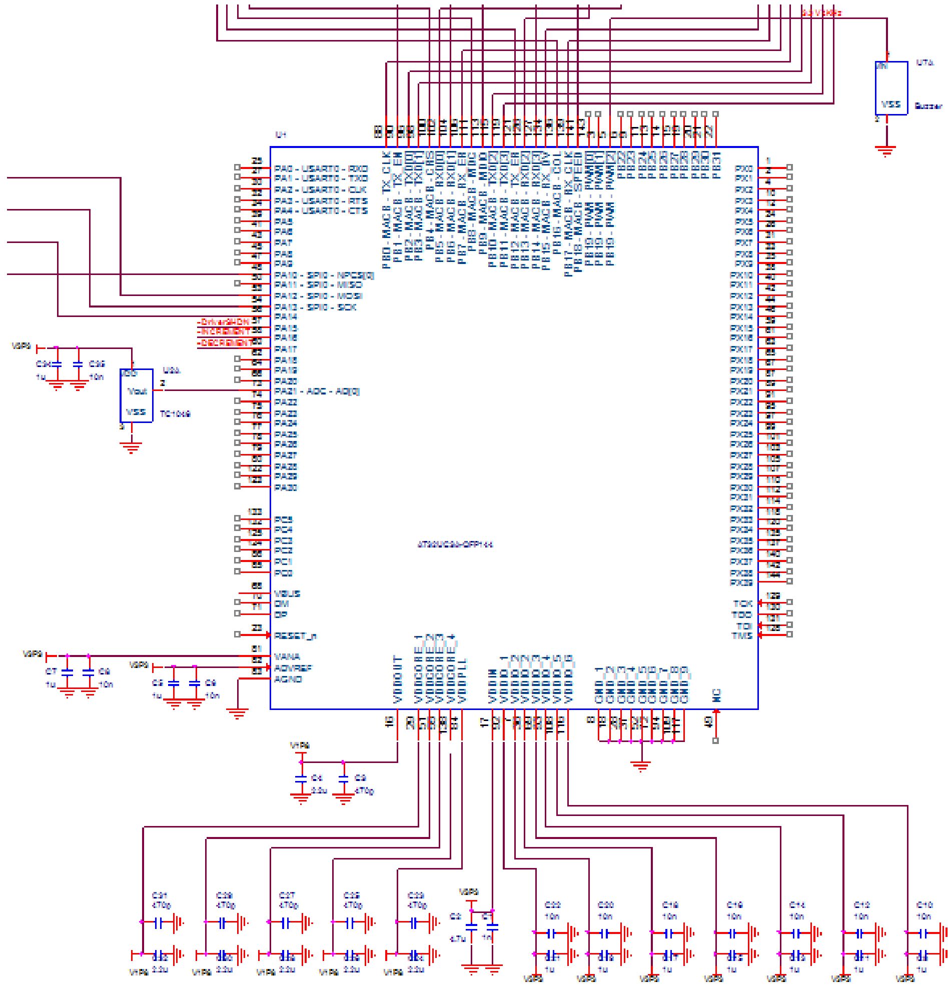
LCD Implementation



Ethernet Design & RJ45 with Integrated Magnetics



Microcontroller Implementation



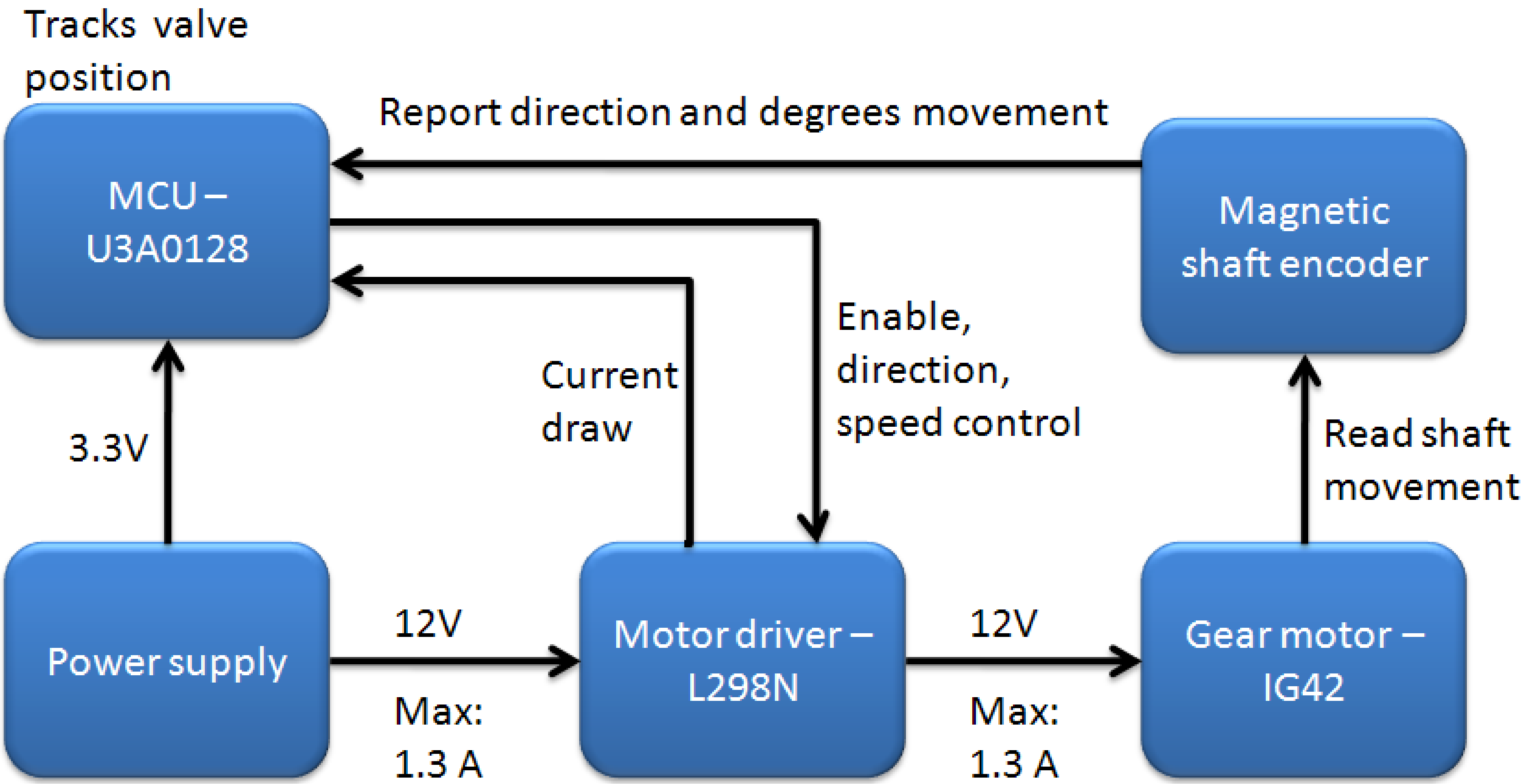
Controller Box Budget

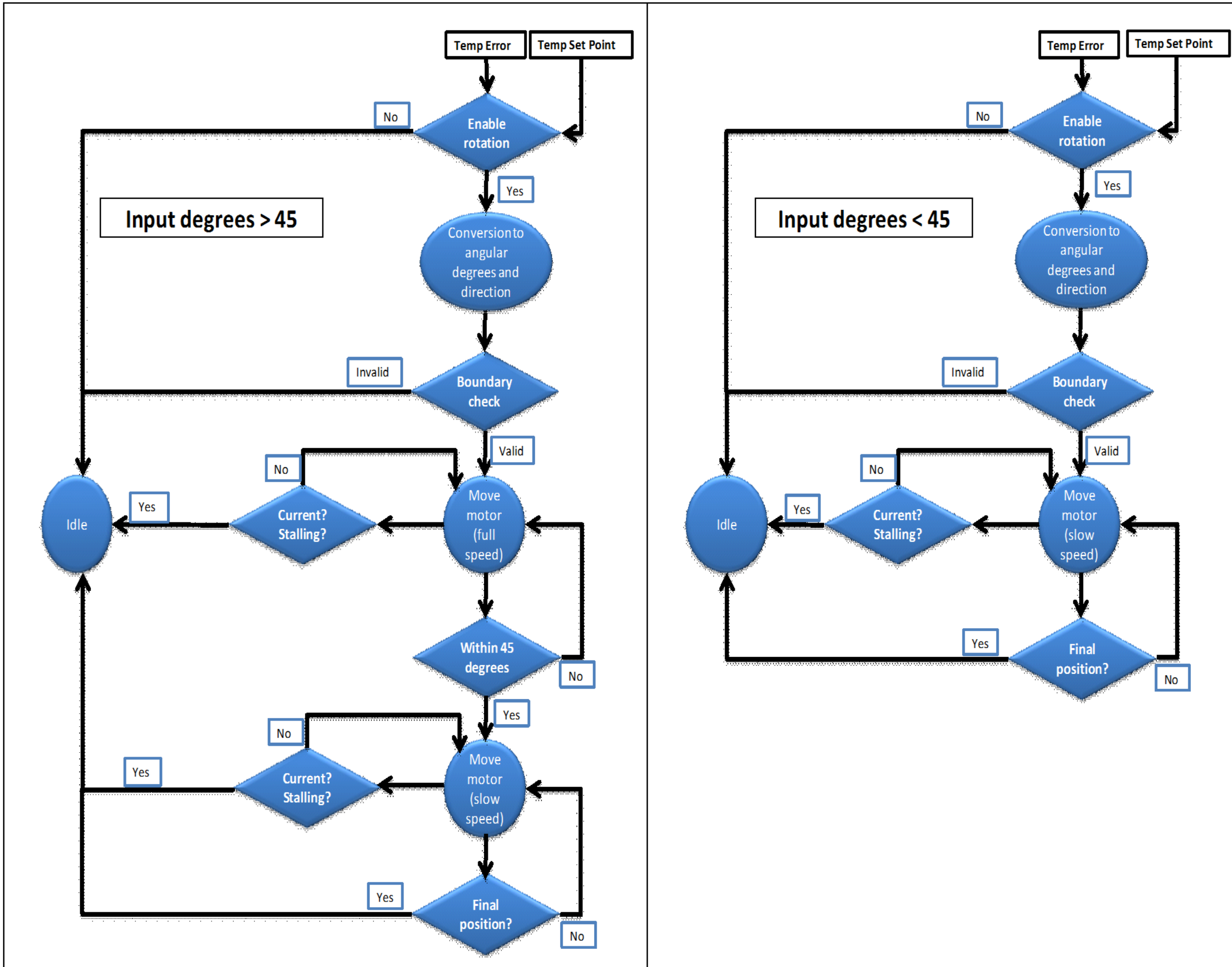
Controller Box					
MODULE	ITEM DESCRIPTION	VENDOR	COUNT	PRICE/UNIT	PRICE
DC motor	IG42 24v gear motor	MPJA	1	$ 59.99	$ 59.99
Motor driver circuit	L298N	Digikey	1	$ 4.78	$ 4.78
Metal platform	Extruded aluminum	80/20	1	$ 15.00	$ 15.00
Tranceiver	Digi Xbee PRO XBee	Digi	1	$ 30.00	$ 30.00
AC to DC power supply	120 V 60 Hz to 12 V DC wall converter		1	$ 19.99	$ 19.99
Miscellaneous components	resistors, capacitors, inductors	ECPE	1	$ 10.00	$ 10.00
Microcontroller	Atmel AT32UC3A0128	Mouser	1	$ 10.00	$ 10.00
Malfunction alarm beeper			1	$ 1.00	$ 1.00
LCD and LCD backlight	DOGM128-6 Electronic Assembly	Mouser	1	$ 22.00	$ 22.00
Ethernet driver	886-LAN8700C-AEZG	Mouser	1	$ 2.28	$ 2.28
PCB			1	$ 33.00	$ 33.00
TOTAL					**$ 208.04**

Control Panel (UI)

Control Panel					
MODULE	ITEM DESCRIPTION	VENDOR	COUNT	PRICE/UNIT	PRICE
Temperature sensor	IC TEMP-VOLT CONV PREC SOT23B	Digikey	1	$ 0.70	$ 0.70
LCD and LCD backlight	DOGM128-6 Electronic Assembly	Mouser	1	$ 22.00	$ 22.00
Transceiver	Digi Xbee PRO XBee	Digi	1	$ 30.00	$ 30.00
Miscellaneous components	resistors, capacitors, inductors	ECPE	1	$ 10.00	$ 10.00
Microcontroller	Atmel AT32UC3A0128	Mouser	1	$ 10.00	$ 10.00
Malfunction alarm beeper			1	$ 1.00	$ 1.00
Battery	2 rechargeable NiMH AA batteries		1	$ 4.00	$ 4.00
USB battery recharging circuit	Maxim DS2712E	Mouser	1	$ 5.13	$ 5.13
PCB			1	$ 33.00	$ 33.00
TOTAL					**$ 115.83**

Functional Diagram




Temp Error
Temp Set Point
Enable rotation
No
Yes
Input degrees > 45
Conversion to angular degrees and direction
Boundary check
Invalid
Valid
Idle
Current? Stalling?
Yes
No
Move motor (full speed)
Within 45 degrees
No
Yes
Current? Stalling?
Yes
No
Move motor (slow speed)
Final position?
Yes
No
Temp Error
Temp Set Point
Enable rotation
No
Yes
Input degrees < 45
Conversion to angular degrees and direction
Boundary check
Invalid
Valid
Idle
Current? Stalling?
Yes
No
Move motor (slow speed)
Final position?
Yes
No

Temp Error to Rotation

- Range: 60˚ – 80˚
- Table for each temperature
- Temperature < 60
  - Fully open
- Temperature > 80
  - Fully close

Temperature Error (degrees Fahrenheit)	Rotation (angular degrees)
-20	Max limit: -1800
-19	.
-18	.
.	.
.	.
.	.
0	0
.	.
.	.
.	.
19	.
20	Max limit: 1800

Mechanical test criteria

Testing Criteria	Satisfactory (Y/N)	Comments
Directional tracking		
Speed control		
Accuracy		within 5 degrees
Torque requirement		greater than 0.95 N m
Debugging interface		report position, direction, current
Recalibration		identify fully closed position
Overcurrent detection		stop operation when current > 1.3 A
Stalling detection		stop operation when motor report stalling
Mechanical stability		operate continuously for 1 week
Electrical stability		operate continuously for 1 week
Operational stability		operate continuously for 1 week

Mechanical Components

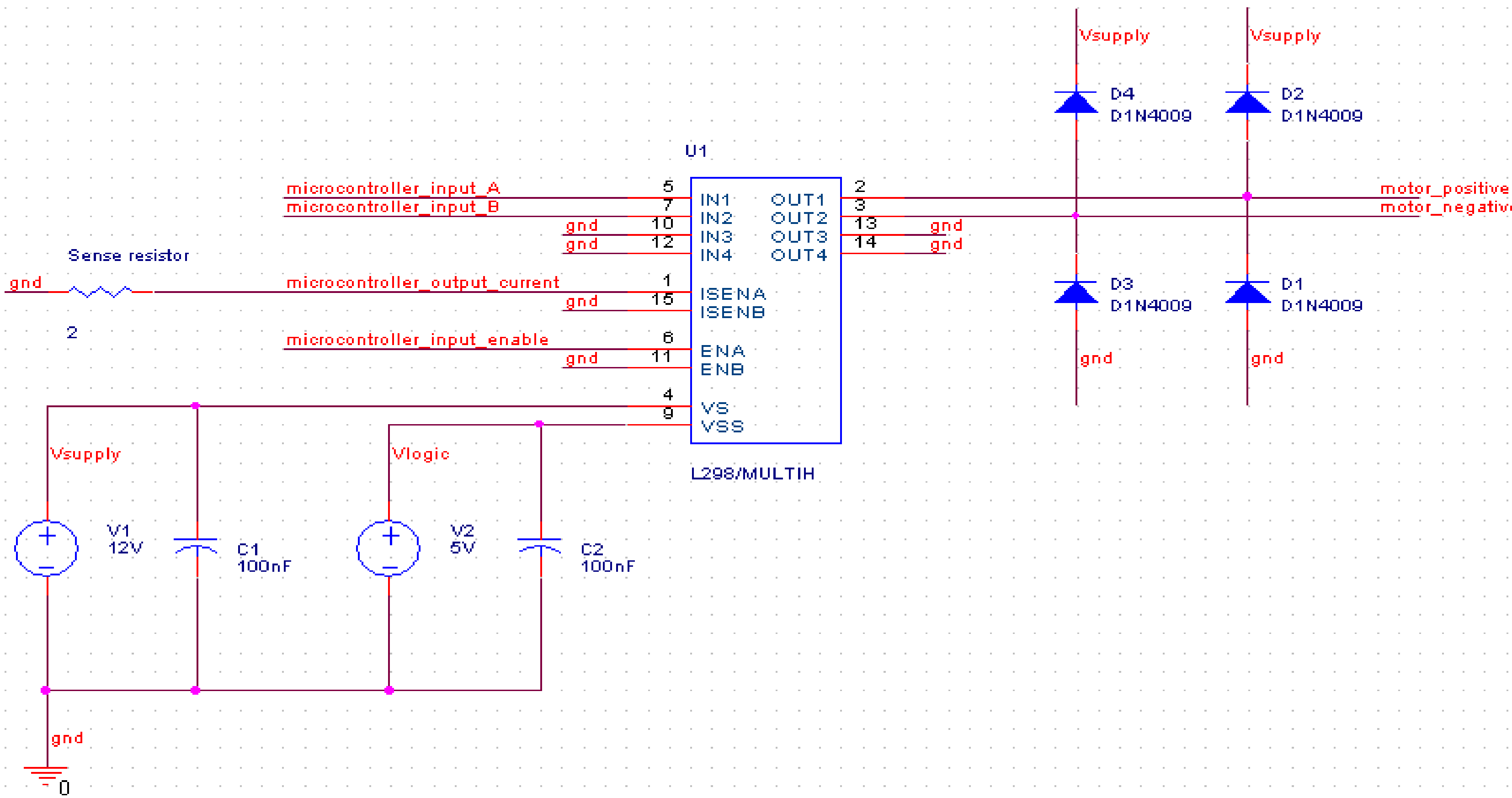
- IG42 Gear motor

Operating at 24 V	Reduction Ratio	Rated Torque (N m)	Rated Speed (rpm)	Rated Current (mA)	No load Speed (rpm)	No Load Current (mA)
	1;84	1.96	75	< 2300	83	< 750

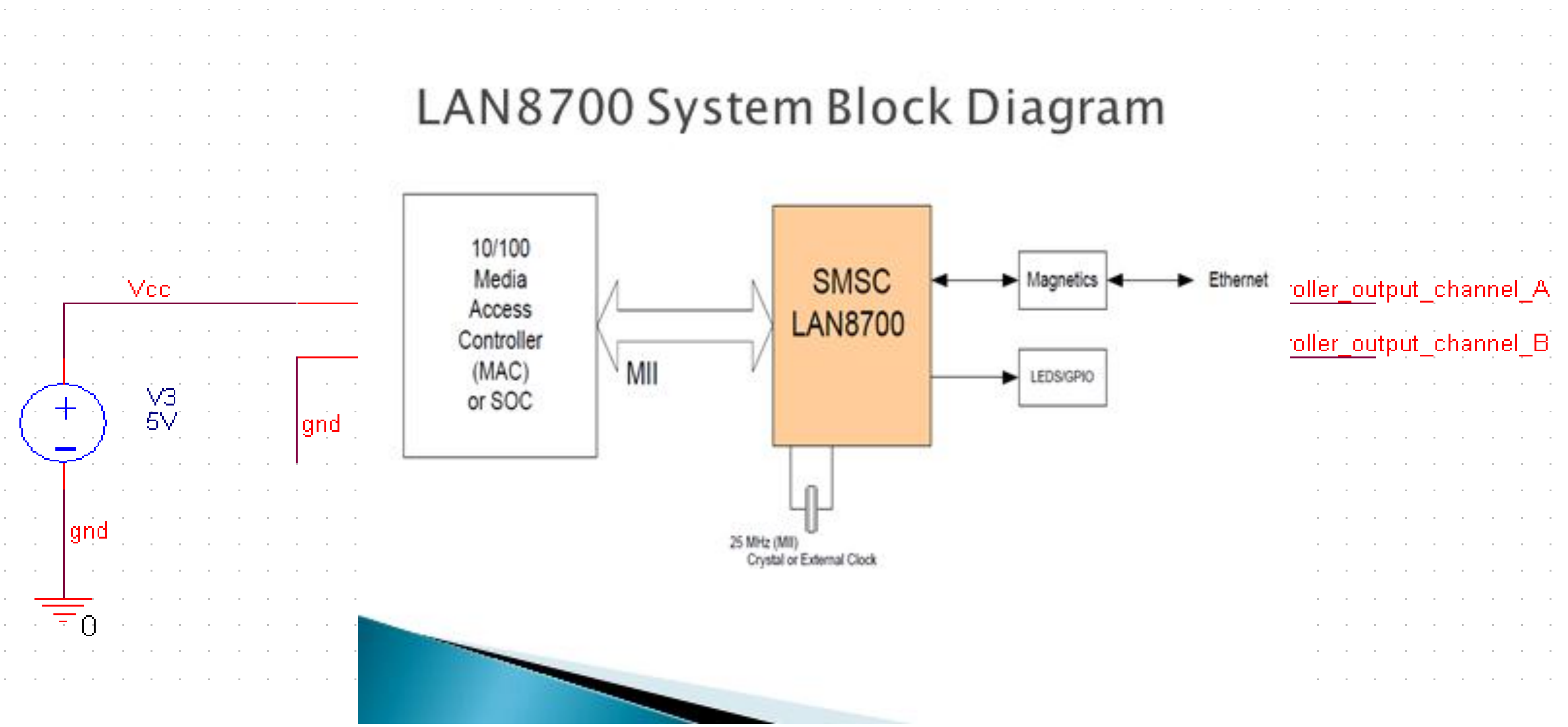
- Shaft encoder

Encoder pulse per rev	Gear Motor Reduction Ratio	Total pulse per rev (after gear reduction)
4	84	336

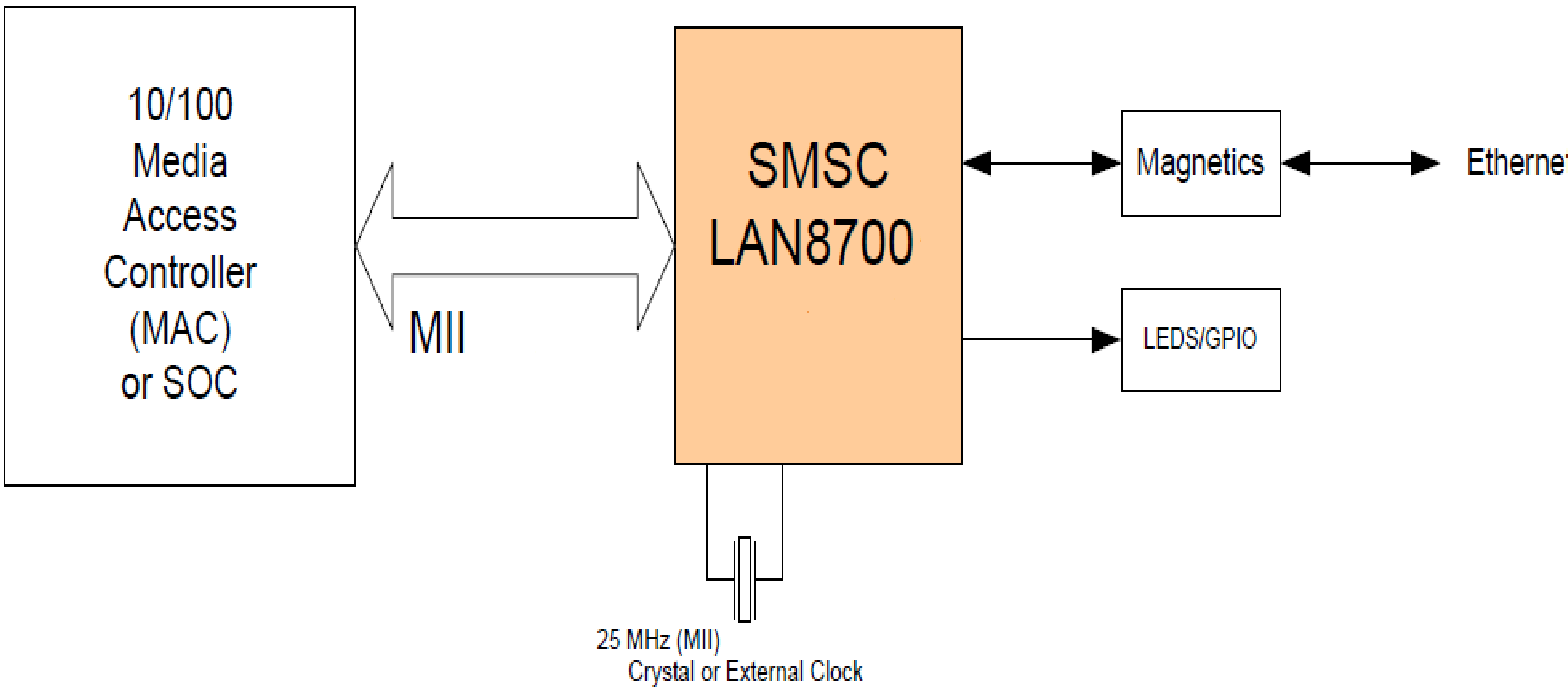
Motor control test circuit



Shaft encoder output circuit



LAN8700 System Block Diagram



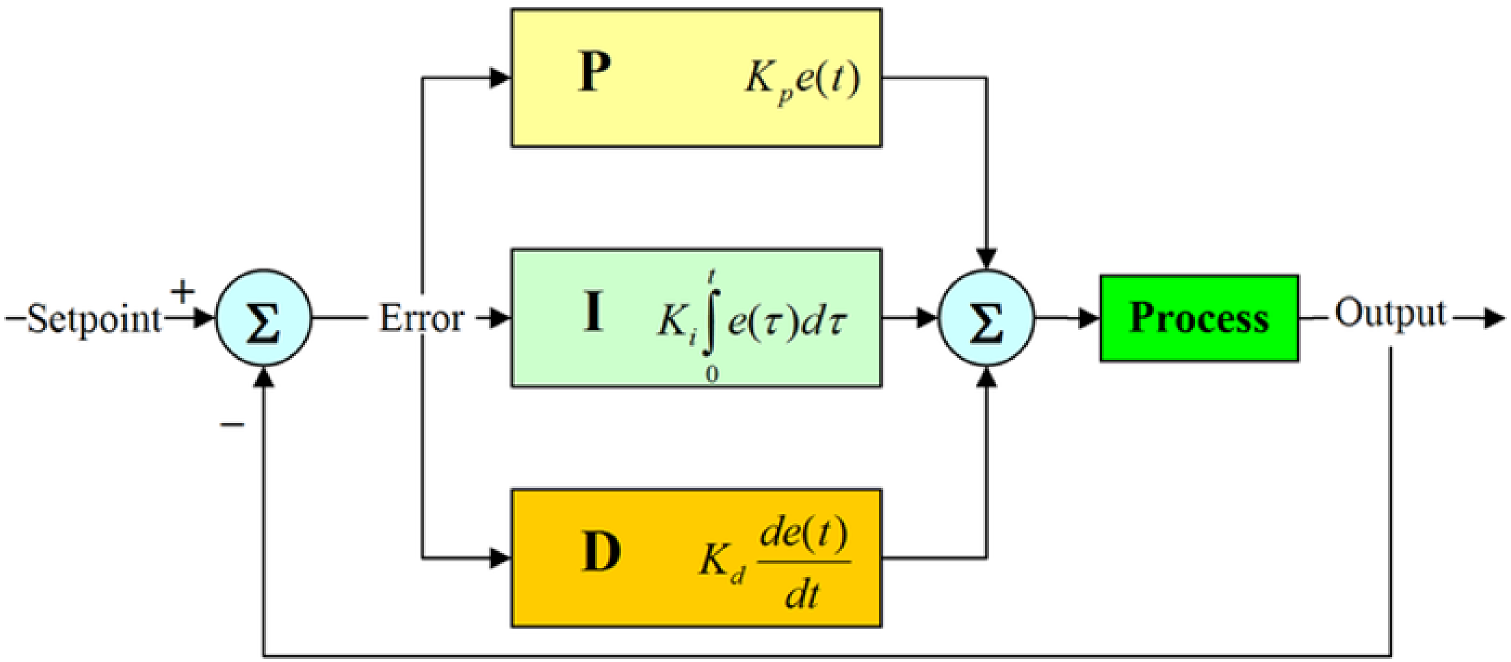
MII Ethernet standard pin mapping

Pin Name	MII	RMII
ETXCK_EREFCK	ETXCK: Transmit Clock	EREFCK: Reference Clock
ECRS	ECRS: Carrier Sense	
ECOL	ECOL: Collision Detect	
ERXDV	ERXDV: Data Valid	ECRSDV: Carrier Sense/Data Valid
ERX0 - ERX3	ERX0 - ERX3: 4-bit Receive Data	ERX0 - ERX1: 2-bit Receive Data
ERXER	ERXER: Receive Error	ERXER: Receive Error
ERXCK	ERXCK: Receive Clock	
ETXEN	ETXEN: Transmit Enable	ETXEN: Transmit Enable
ETX0-ETX3	ETX0 - ETX3: 4-bit Transmit Data	ETX0 - ETX1: 2-bit Transmit Data
ETXER	ETXER: Transmit Error	

DMA controller's types of operation

- Receive buffer manager write
- Receive buffer manager read
- Transmit data DMA read
- Receive data DMA write
- Transmit buffer manager read
- Transmit buffer manager write

PID Algorithm



PID Controller Difference Equation

$$s = \frac{1 - z^{-1}}{T_s} \qquad T_s = Sampling\ Period$$

$$H(s) = \frac{u(s)}{e(s)} = k_p + \frac{k_I}{s} + k_D s$$

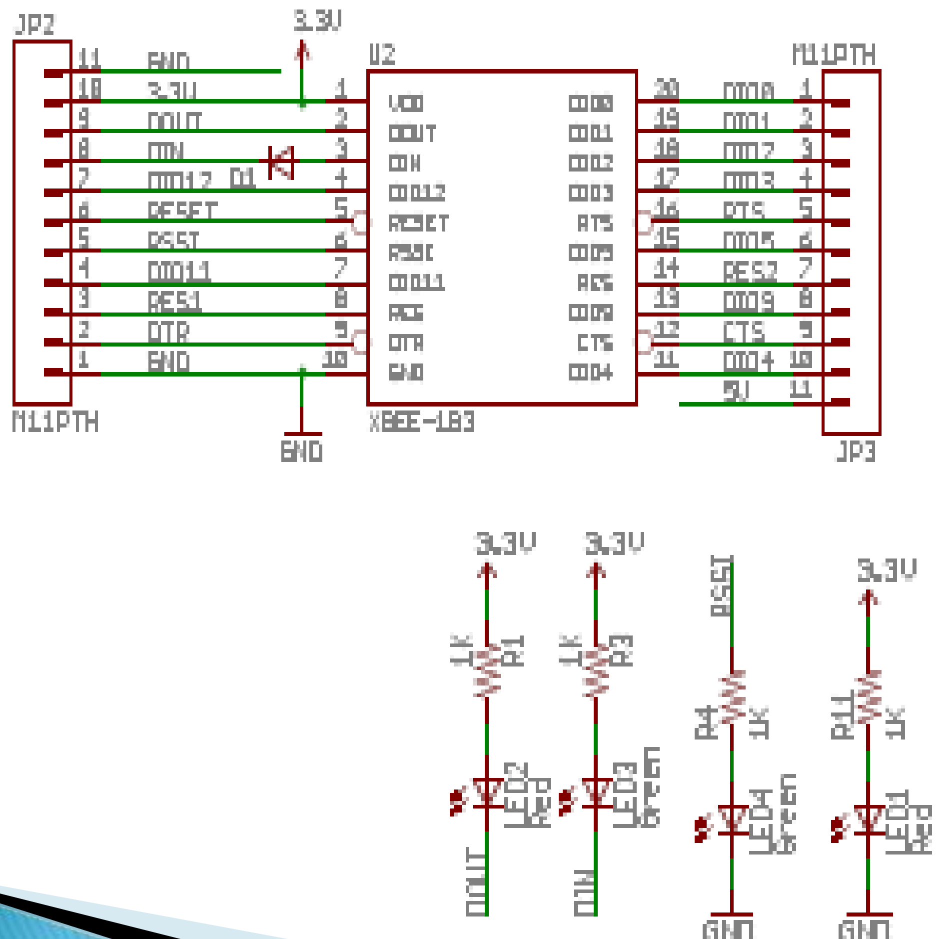
$$H(z) = k_p + \frac{k_I}{\frac{1-z^{-1}}{T_s}} + k_D \frac{1 - z^{-1}}{T_s}$$

$$H(z) = k_p + \frac{k_I T_s}{1-z^{-1}} + \frac{k_D}{T_s}(1 - z^{-1})$$

$$u(z) = u(z)z^{-1} + k_p(1 - z^{-1})e(z) + k_I T_s e(z) + \frac{k_D}{T_s}(1 - z^{-1})^2 e(z)$$

$$u(t) = u(t-1) + k_p e(t) - k_p e(t-1) + k_I T_s e(t) + \frac{k_D}{T_s}\big(e(t) - 2e(t-1) + e(t-2)\big)$$

Xbee connections



Pin Connections		
PIN	PIN name	Connection
1	VCC	3.3v power supply
2	DOUT	UART Out/LED
3	DIN/CONFIG	UART In/LED
4	D08	NC
5	RESET	GPIO
6	PWM0/RSSI	GPIO
7	PWM1	NC
8	[reserved]	NC
9	DTR/SLEEP_RQ/DI8	GPIO
10	GND	GND
11	AD4/DIO4	GPIO (optional)
12	CTS/DIO7	GPIO
13	ON/SLEEP	GPIO/LED
14	VREF	NC
15	Associate/AD5/DIO5	GPIO
16	RTS/AD6/DIO6	GPIO
17	AD3/DIO3	GPIO (optional)
18	AD2/DIO2	GPIO (optional)
19	AD1/DIO1	GPIO (optional)
20	AD0/DIO0	GPIO (optional)

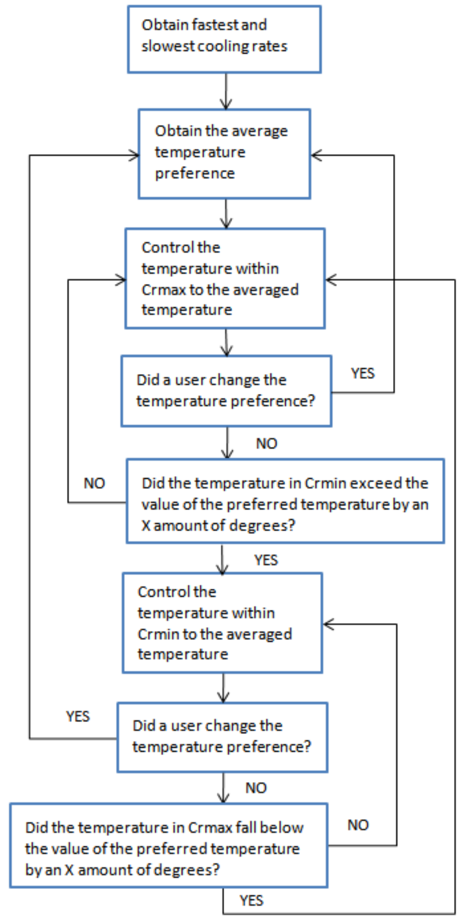
Hardware Test Plan

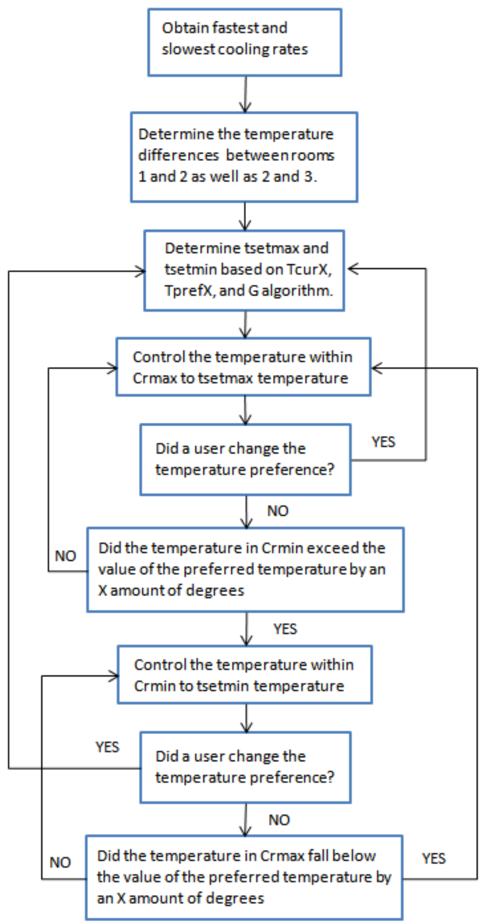
Section	Satisfactory Y/N	Notes	Comments
Power:			
Test voltage levels, voltage ripple, voltage stability, and voltage behavior due to transients of all power supplies over their full loads			
Test the limits on inputs to all switchers and LDOs			
Test typ. current draw for all major power rails			
Test typ. noise levels on all major IC power rails			
Test the limits of all voltage limiter circuits			
Test reverse protection circuitry			
Ensure proper power supply sequencing			
Microprocessor:			
Test high speed signal lines for signal integrity:			
SPI signal integrity CD lines			
USART signal integrity on transceiver lines			
Ethernet signal integrity on the transceiver lines			
PWM lines on motor driver lines			
Test system reset functionality			
Test microprocessor can be JTAGed and programmed as needed			
Test microprocessor can communicate to LCD, Xbee transceiver, Ethernet Transceiver, and motor driver circuit - proper handshake sequencing			
Test RJ-45 and USB port lines for proper level conversion			
Test LED systems to determine if operating in safe current limits			
Ensure proper clock start up sequence			
Ethernet Transceiver:			
Test high speed signal lines for signal integrity:			
Ethernet signal integrity on the microprocessor lines			
Ethernet signal integrity on the RJ45 lines			
Test system Reset functionality			
Test transceiver can communicate to Iowa State University network and vice versa			
Test Ethernet Transceiver communication to microprocessor			
NiMH Charger:			
Test for appropriate charging rate and level			
Test charger reset functionality			
Test charger safety shutoff functionality			
Test charger system power and battery charging multitask capability			
Push Buttons:			
Test for noise, bounce, and transient levels during switching for slider switches and momentary push buttons			
Test for proper signal rise/fall times during switching for slider switches and momentary push buttons			
Unit casings:			
ESD testing to determine the quality of design			
Temperature sensitive testing in order to determine endurance			
LCD:			
Test under temperature limits to determine quality dynamics and mitigate adverse effects			
Test under various lighting conditions to determine proper backlight strength			
Temperature sensor:			
Test accuracy of the temperature sensor in various environmental conditions			
Test limits of operational temperature			
DC Motor:			
Test operation under extensive temperature range			
Test output torque and make certain that it meets required specification			
Test quality of performance using different driver circuits			

Functional Test Plan

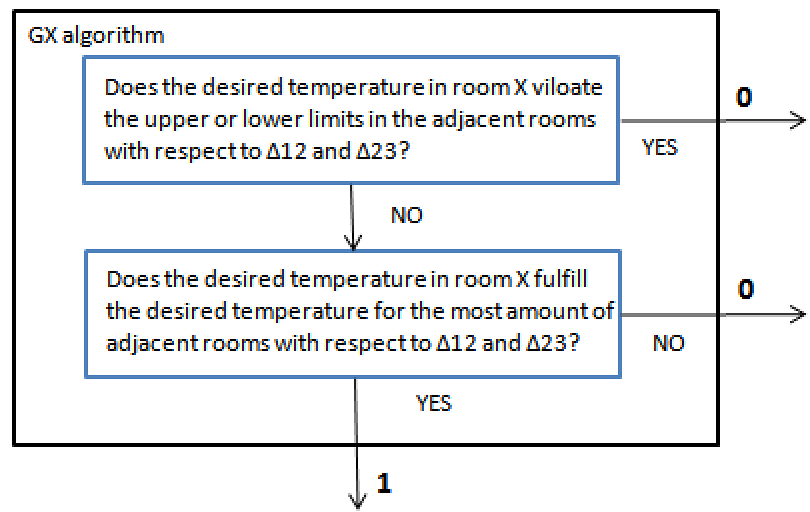
Functional Testing		
Basic Functionality		
Test	Success (P/F)	Criteria
temperature set pt. is higher than the current temp		valve opens more
temperature set pt. is lower than the current temp		valve closes more
set temperature preference and then check to see if set pt. is reached		valve is close (within 20% of turn range) to being closed
Set all preferences to 68^o		temperature is set to within 2^oc after
Stand 3 ft. away from the LCD and read the temperature		LCD is visible, can be read from 3 feet away
Attempt go below the lower temperature limit of 60^of		UI should stay at 60^of
Attempt go above the upper temperature limit of 80^of		UI should stay at 80^of
Valve Calibration		
Test	Success (P/F)	Criteria
Increment temperature preference by one ^{o}F starting from 60 to 80.		valve should open slightly more each time the temperature preference goes up
Decrement temperature preference by one ^{o}F starting from 80 to 60.		valve should close slightly more each time the temperature preference goes down
Range Tests		
Test	Success (P/F)	Criteria
Send one message to the transceiver at each range between 0 walls to 4 walls		Range of up to 300 ft. with up to 4 walls between the UI and the control box
Send 100 messages to farthest range (300 ft., 4 walls)		Have 95% of sent messages received successfully
Response Test		
Test	Success (P/F)	Criteria
User sets temperature to 78^oF from 72^oF		The room should reach approximately 78^oF in two hours
User sets temperature to 72^oF from 78^oF		The room should reach approximately 72^oF in two hours
Equalization and weighting Test		
Test	Success (P/F)	Criteria
Start from temperature set point of Room1: 75, Room2: 78, Room3: 83		The room should reach approximately 78^oF depending on states
Start from temperature set point of Room1: 60, Room2: 75, Room3: 85		The room should reach approximately 75^oF depending on states
Environmental and extreme Tests		
Test	Success (P/F)	Criteria
Put the steam valve control system in the oven at 100^oF		Controller box functions after running for 10 hrs. in 100^oF
Put the steam valve control system in the fridge at 100^oF		Controller box functions after running for 10 hrs. in 10^oF Temperature
Set all preferences to maximum		The temperature is set to within 2^oF
Set all preferences to minimum		The temperature is set to within 2^oF
Power and Charging		
Test	Success (P/F)	Criteria
Plug the controller into the USB when the battery level is at 50%		The unit indicates charging state
Drain the controller battery level to less than 10%		The buzzer sounds indicating low battery state
Plug the controller into the USB when the battery level is at 100%		The unit will indicate charging complete state
Monitored extended use testing		
Test	Success (P/F)	Criteria
Run system for 1 week, monitoring the temperature		The temperature is set within one time constant
Run system for 1 week, monitoring the LCD quality		The contrast of the LCD should remain the same, the LED backlighting should be at medium brightness
Press push buttons over 300 times		The incrementing and decrementing of the temperature should be functional

Set Point Algorithm





Obtain fastest and slowest cooling rates
Determine the temperature differences between rooms 1 and 2 as well as 2 and 3.
Determine tsetmax and tsetmin based on TcurX, TprefX, and G algorithm.
Control the temperature within Crmax to tsetmax temperature
Did a user change the temperature preference?
YES
NO
Did the temperature in Crmin exceed the value of the preferred temperature by an X amount of degrees
NO
YES
Control the temperature within Crmin to tsetmin temperature
YES
Did a user change the temperature preference?
NO
Did the temperature in Crmax fall below the value of the preferred temperature by an X amount of degrees
NO
YES



GX algorithm
Does the desired temperature in room X viloate the upper or lower limits in the adjacent rooms with respect to Δ12 and Δ23?
YES
0
NO
Does the desired temperature in room X fulfill the desired temperature for the most amount of adjacent rooms with respect to Δ12 and Δ23?
NO
0
YES
1

Power Supply