Steam Valve Controller

Design Report

F10-19

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List of Definitions

Alternating current (AC) (hardware) - The movement of electric charge periodically reverses direction.

Analog-to-digital converter (**ADC**) (hardware) - A device that converts a continuous quantity to a discrete digital number.

Boost Converter (hardware) - used to step up a voltage to a particular level given an input voltage by switching a transistor and using circuit elements to store energy.

Buck Converter (hardware) – A device used to step down a voltage to a particular level given an input voltage by switching a transistor and using circuit elements to store energy.

Complementary metal-oxide-semiconductor (CMOS) (hardware) - A technology for constructing integrated circuits.

Controller Box (hardware) - A module that holds all the electrical components that rotates the steam valve.

Direct current (DC) (hardware) - The unidirectional flow of electric charge.

Emitter-coupled logic (ECL) (hardware) - A logic family that achieves high speed by using an overdriven BJT differential amplifier with single-ended input.

Ethernet (hardware) - A family of frame-based computer networking technologies for local area networks (LANs).

General Purpose Input/Output (GPIO) (hardware) - An interface available on some devices to interface with external devices and peripherals.

IEEE 802.15.4 (hardware and software) - A wireless communication standard under the IEEE 802.15 standards for Wireless Personal Area Networks, currently used as a medium for a wide variety of network protocols including Xbee.

IEEE 802.3 (software) - a working group and a collection of IEEE standards produced by the working group defining the physical layer and data link layer's media access control (MAC) of wired Ethernet. This is generally a local area network technology with some wide area network applications.

LDO (hardware) – Low Dropout Regulator, a device used to achieve a given output voltage given an input voltage by burning energy.

Liquid crystal display (LCD) (hardware) - A thin, flat electronic visual display that uses the light modulating properties of liquid crystals.

Media Independent Interface (MII) - a standard interface used to connect a Fast Ethernet (i.e. 100 Mbit/s) MAC-block to a PHY chip. The MII may be used to connect the MAC to an external PHY via a pluggable connector (see photo), or to connect a MAC chip to a PHY chip on the same printed circuit board.

NiMH – NiMH is a particular technology used in rechargeable batteries.

Plant (hardware) - The steam valve.

Power Supply Sequencing (hardware) – The start up times of the power system.

Printed Circuit Board (PCB) (hardware) - Used to mechanically support and electrically connect electronic components using conductive pathways, tracks or signal traces.

Proportional–integral–derivative controller (PID controller) (hardware) - A generic control loop feedback mechanism (controller) widely used in industrial control systems.

Reduced Media Independent Interface (RMII) - a standard that addresses the connection of Ethernet physical layer transceivers (PHY) to Ethernet switches. It reduces the number of signals/pins required for connecting to the PHY from 16 (for an MII-compliant interface) to between 6 and 10. RMII is capable of supporting 10 and 100 Mbit/s; gigabit interfaces need a wider interface.

Serial Peripheral Interface Bus (SPI) (hardware and software) - A synchronous serial data link standard named by Motorola that operates in full duplex mode.

Signal Integrity (hardware) – Rise and fall times of signals on signal lines.

Switcher (hardware) - A buck converter used to step down a voltage to a particular level given an input voltage by switching a transistor and using circuit elements to store energy.

Transceiver (hardware) - A device that has both a transmitter and a receiver combined and share common circuitry or a single housing.

Transistor–transistor logic (TTL) (hardware) - A class of digital circuits built from bipolar junction transistors (BJT) and resistors.

Universal asynchronous/synchronous receiver/transmitter (UART/USART) (hardware) - A type of "asynchronous receiver/transmitter", a piece of computer hardware that translates data between parallel and serial forms.

User Interface (hardware and software) - synonymous with Control Panel.

Executive Summary

Iowa State University buildings built prior to the late 1960's utilize steam valves and radiators to heat rooms. These heating systems link multiple rooms through steam pipes and consist of a single valve that controls the temperature heat output through radiators within each room. The user does not have knowledge of the magnitude of revolutions needed to accommodate a desired temperature within the room and causes over and under heating throughout the rooms. Since these heat systems consist of physical controls, Facilities Planning and Management does not have remote access to the system in order to regulate temperature in times of little to no occupancy. As a result, significant energy is lost during campus night hours and school breaks, consequently increasing energy bills.

In order to solve these issues, our group has proposed to perform a system level integration in which we will design a steam valve controller unit and a user interface unit. The steam valve controller unit will consist of a DC motor - used to rotate the steam valve, a microcontroller - used to run the control algorithm, a wireless transceiver - used to communicate to the user interface, and Ethernet connectivity – used to connect to the Iowa State network. The user interface will consist of a LCD display – human machine interface, push buttons – used to receive user input, a temperature sensor – used to record the room temperature, a wireless transceiver - used to communicate to the steam valve controller, and a microcontroller - used to control the user interface unit. Through design, we will integrate these components into an efficient temperature control system.

The end product will consist of two units: the user interface and the steam valve controller. The user interface will be a wall mountable unit similar to a thermostat. It will prompt for and accept temperature values from users. The unit will also be used as a means of sensing and recording current room temperature. It will communicate the current room temperature and user input temperature values to the steam valve controller unit. The controller unit will resemble a box structure and will be situated on top of the steam valve. It will run an algorithm based on received temperature values and adjust the steam valve appropriately through the DC motor. This system will allow user friendly temperature control and monitoring.

The only major issue that the group foresees is a shortened project deadline. Our product will be used throughout winter. Unfortunately, this is the only time that steam heat will be available. This means that our final prototype must be ready before the end of winter in order to finish final testing and assure that the product works as expected. Our group will have to put in extra effort in order to accommodate this change in schedule.

Acknowledgement

Our team would like to thank Lee Harker and Jason Boyd for their contributions to the project. Not only are they our clients, but they also serve as valuable resources throughout the project. Instead of just providing our team with just a description of the project, they have been proactively working with us to adapt the project to meet their needs and ensure the highest chance of success.

We are thankful for the opportunity to work with such enthusiastic advisors like Lee and Jason, and acknowledge all their contributions to the project.

Problem statement

Buildings at Iowa State University built prior to the late 1960's utilize steam valves and radiators to heat rooms. The controls of these heating systems consist of steam pipes and simple knobs that allow the user to adjust the flow of steam through the radiator, thus adjusting the temperature.

It is common for one steam valve to control temperature throughout several different rooms. The problem arises from the heat gradient between these rooms, created when the steam valve is adjusted too high or too low. The user does not have knowledge of the magnitude of revolutions needed to accommodate a desired temperature within the various rooms. In result, the user must constantly adjust the valve in order to accommodate a desired temperature, leading to over and under heating of the system of rooms.

Since these valves are spread across remote areas of buildings and consist only of physical controls, Facilities Planning and Management have no control over temperature ranges during times of little to no occupancy of rooms. In result, significant energy is lost during campus night hours and school breaks, consequently increasing energy bills.

Coover, the electrical and computer engineering building, utilizes this steam system. Within Coover, radiators are used to heat a multitude of adjacent rooms and steam valves are used to control temperature. In extreme cases, one steam valve controls the temperature in five different rooms through five radiators. This creates a temperature gradient across the rooms and requires continuous adjustment of the steam valve in order to accommodate the individuals within each room.

The steam pipes run along one side of the room's perimeter, sit approximately a foot off of the ground, and are routed through walls, floors, and ceilings. There exists only one steam valve control for a number of adjacent rooms. From this constraint, it is evident that there will need to be a unit placed on the valve that adjusts the valve to control the temperature in the system of rooms. Since this unit will control temperature conditions in several rooms, a device will be needed in each room that will sense each of the temperatures. The piping route through walls, floors, and ceilings restricts wired communication between temperature sensors and creates a need for a wireless communication between sensor units and the steam valve controller unit.

The most important mechanism of the project is the user interface that allows the user to control the temperature within each room. Since several rooms are governed by one steam valve and multiple individual users, a user interface will be required in each room. In that respect, the steam valve controller will accommodate an averaged input temperature. Because the pipes are low to the ground and are in remote areas, the user interface will be a separate unit from the steam valve controller. Remote override access into the system and temperature control will be provided for Facilities Planning and Management because they will be in charge of controlling room temperature throughout Coover.

Our group has formulated a general solution approach to this problem. In order to rotate the valve, we will utilize a DC motor. The motor will be connected to control circuitry that will run an algorithm based on the temperature in the various rooms and force the valve to adjust appropriately. The control circuitry will utilize wireless communication schemes in order to communicate back and forth between the temperature sensors.   The controller unit - DC motor and control circuitry- will need to draw a lot of power in order to turn the valve and will therefore will require an outlet plug in. In order to provide Facilities Planning and Management with override access to set and control temperature, we will integrate an Ethernet port into the steam valve controller unit with access to the Iowa State University network.

In order to receive desired temperature inputs from users, we will utilize a separate user interface wall mountable unit. This unit will consist of a backlit LCD display and several push buttons that allow users to access menus and set desired options. Integrated into this unit will be a temperature sensor that will read the current room temperature and communicate this information to the steam valve controller unit. Another feature integrated into the user interface is a small speaker that will sound when an error or hardware malfunction occurs. Since this is a low power unit and highly digital unit, it will run off of regular AA batteries.

Operating Environment

The end product consists of two different units that will operate in two different environments. These two products will operate in offices and classrooms throughout Coover and ideally throughout various buildings at Iowa State University. The user interface will regularly operate at room temperature and will occasionally experience temperatures ranging from 50 degrees Fahrenheit to 90 degrees Fahrenheit. The unit will be situated on the wall via a mounting device and may experience a drop upon installation or an occasional bump from a passerby. It will be exposed to mildly dusty conditions and operate in an open environment. The unit will experience various forms of humidity and sunshine but will be sheltered from the weather elements such as rain and snow. Because it will be located in a busy environment, it will experience everyday use.

The controller box will be situated directly on top of the steam valve and will thus operate at temperatures ranging from 50 degrees Fahrenheit to 120 degrees Fahrenheit. It will constantly be exposed to highly dusty conditions and will operate in open environments and tight spaces. The unit will experience various forms of humidity and sunshine but will be sheltered from the weather elements such as rain and snow. It may experience the occasional bumps from nearby objects. Because the controller has to maintain the desired temperature, it will experience continuous use.

Intended User(s) and Intended Use(s)

Intended users of our product, the user interface unit, will be Iowa State University students and faculty members. The users will be young adults – early to late twenties, of various sizes, both male and female, and will have a college education. The majority of use will come from students and professors. They will be tired from work and studies and therefore require a simple, easy to use interface. These individuals will come from varying ethnic backgrounds; therefore reducing the amount of text based commands will benefit usability.

The end product is expected to be used as a means of controlling the temperature to an appropriate level across various rooms by the individuals within them as well as Facilities Planning and Management during times of low to little occupancy. The product is used to help cut heat cost when individuals are not present and maintain a constant temperature when individuals are present. Through implementation, the end product eliminates the possibility of one individual dictating the temperature across various rooms and removes ambiguity from temperature setting. It also gives Facilities Planning and Management the power to set and regulate temperature across various rooms in which they have no current control over.

Assumptions and Limitations

Assumptions:

- Iowa State University students and faculty will use this product.
- This product will not be used outside of the United States.
- This product will be used indoors.
- Users of various ethnic backgrounds, age groups, and genders will use this product.
- This product will be used in rooms of varying sizes, sunlight exposure, and temperature sensitivities.
- The maximum number of simultaneous users for the product will be five.

Limitations:

- The end product will have to communicate wirelessly between components.
- The end product has to have Ethernet connectivity.
- Our group has limited experience with mechanical implementation – product casing and situating.
- Temperature gradient across rooms will cause constant temperature offset.
- There exists only one valve for various rooms.
- Financial budget.

- Plant restrictions (volume of steam/heat output).
- Conflicting Temperature Preferences.
- Part's lead time.
- The controller box must be able to operate on 60 Hz 120 V.
- The user interface must be operable using standard AA batteries.
- Both units must withstand dust accumulation.
- The end product needs to be completed prior to May 2011.
- Prototype testing must occur during the winter months.

Expected End Product and Other Deliverables

Prior to the end of the project in April 2011, our team will deliver one controller box, one control panel, and project design documentation.

Controller Box

The controller box will include the metal platform, the mechanical components, microcontroller, the PCB housing all the electronics, the transceiver, the Ethernet module, and the power supply. The controller box will be designed to fit and securely about the steam valve. There will be a metal bar connecting the DC motor to the steam valve allowing it to turn clockwise and counterclockwise.

The controller box will use a power supply fed by the wall electrical outlet to supply power to the controller box. The PCB board within the controller holds all the major electronics. The PCB will contain a LCD to display status information and product debugging. The transceiver will allow wireless communication between the controller box and control panels. The controller box will use the transceiver to receive information on temperature set point and room temperature measurement.

The Ethernet module will allow communication through the ISU network. The microcontroller will control all the modules on the PCB board. The microcontroller will send and receive information through the Ethernet connection to remotely configure the controller box. Our clients will have a web interface to view and configure the controller box through the Ethernet connection. Lastly, the controller box will have a buzzer that will sound in case the unit malfunctions.

Control Panel

The control panel will include an LCD display, push buttons, microcontroller, temperature sensor, buzzer, transceiver, two rechargeable NiMH AA batteries, and along with rechargeable circuitry. There will be an on board microcontroller that will handle the LCD, temperature sensor, buzzer, and transceiver. The LCD display will output current temperature of the room and the desired temperature set by the user.

The microcontroller will send the user's input data and the temperature sensor's readings to the transceiver which in turn will send that wirelessly to the controller box located on top of the steam valve. The control panel will have a buzzer that will sound in case of malfunction. The control panel will be modularized and multiple control panels can communicate to a single controller box. The range of the control panel to the controller box will be limited by the transceiver. Our clients want the range to be around 300 meters indoors. The two AA batteries will power the control panel. Lastly, the control panel will have an outer casing that allows it to be convenient attached to the wall.

Approach Used

The nature of the project is of integrating a variety of components together to create a system that will accomplish our functional and non-functional requirements. The overall design of the system, shown in figure 1, gives an overview of how each sub-system contributes to meeting the requirements of the system. Our project consists of two basic sub-systems, the controller box and the control panel, outlined in figures 3 and 4 respectively. Each of these sub-systems has a number of components which have their own selection and design considerations.

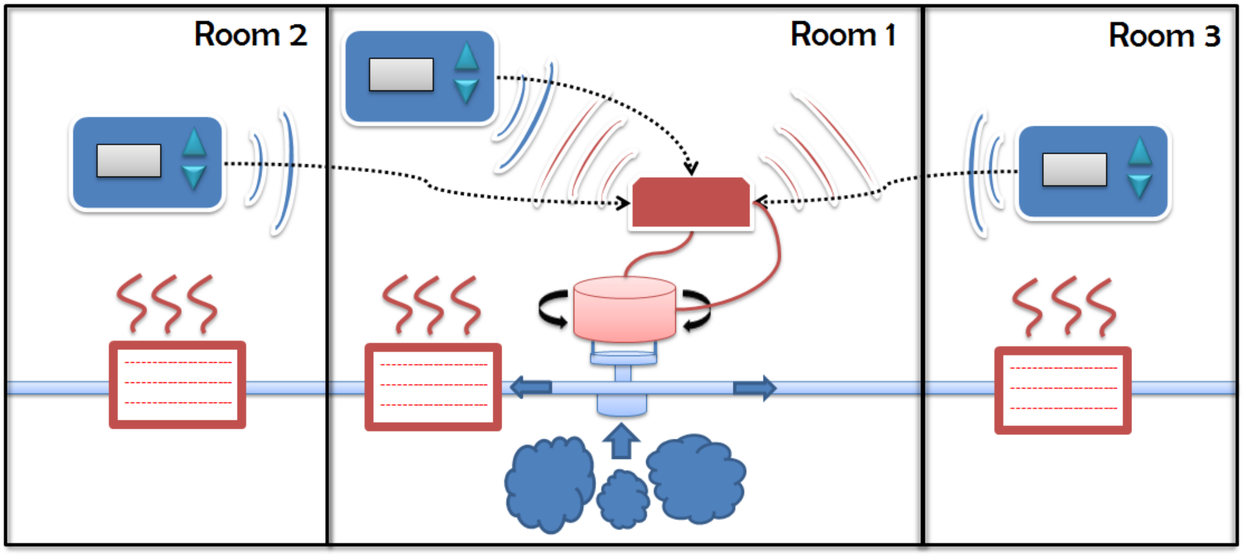


Figure 1: System Concept Sketch

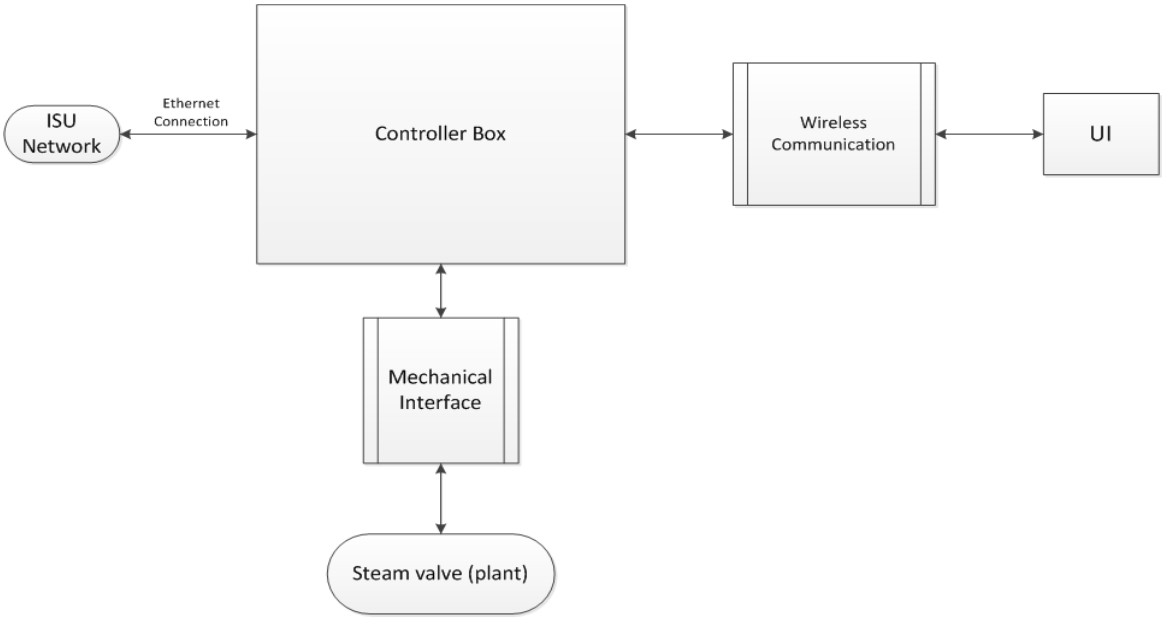


Figure 2: System Level Design

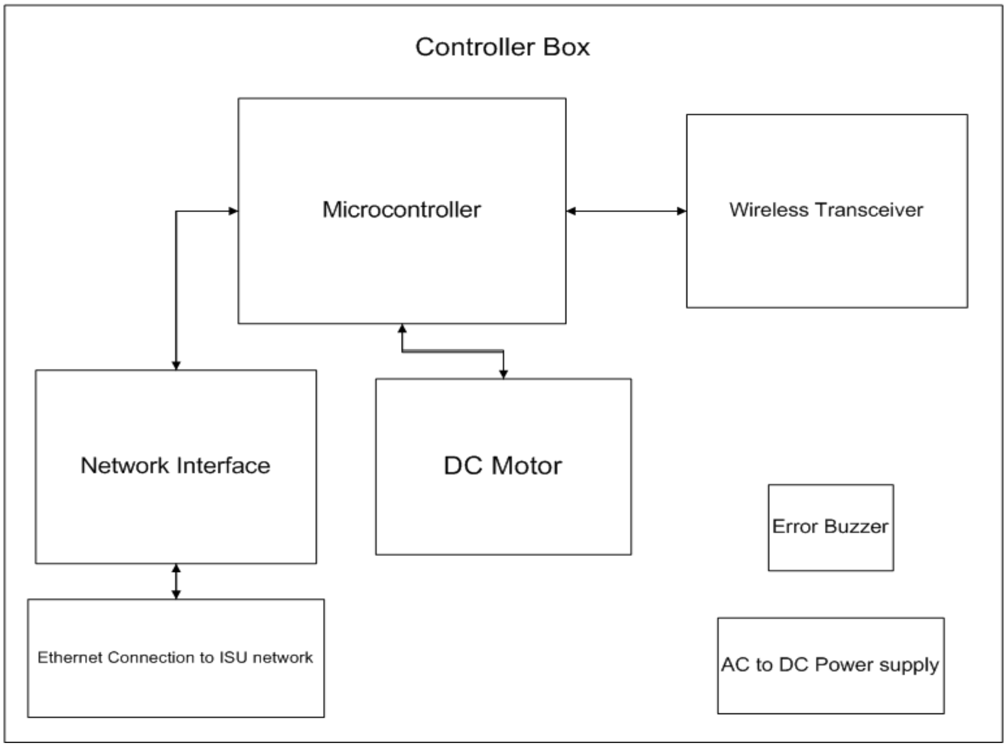


Figure 3: High Level Design of the Controller Box

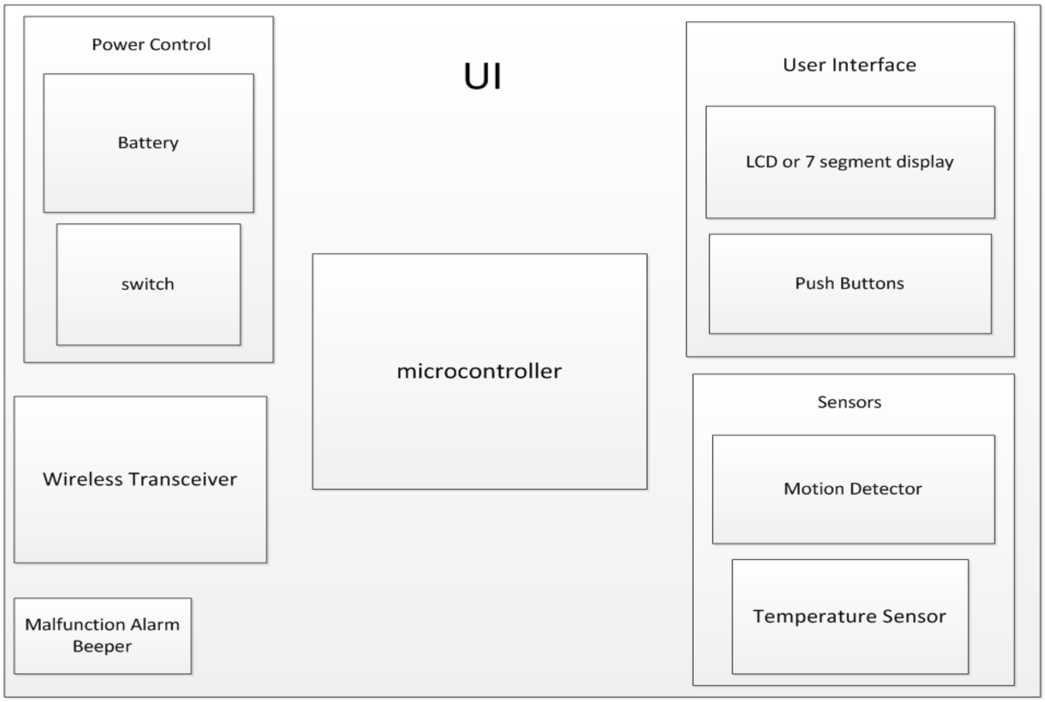


Figure 4: High level Design of the Control Panel

Design Objectives

- The controller must be able to control the temperature in up to 5 adjacent rooms using wireless communication.
- The steam valve controller must be able to communicate through the Iowa State network using Ethernet
- The unit must be capable of being detached from the steam valve without effecting the steam pipes
- Design must be capable of being mass produced and used in a variety of environments
- The interface must be user friendly

Functional Requirements

The project has functional requirements that revolve around the product's intended use as a thermostat. It has to imitate many of the capabilities of a modern heating system while utilizing existing heating methods. The functional requirements of the product include:

1. **Effectively control the temperature in the room**: The most important functional requirement is that the controller must be able to effectively control the temperature by adjusting the attached steam valve appropriately.
2. **Take occupant's preferences**: The unit must have a user interface that allows the occupant to specify a temperature preference.
3. **Multiple room control**: There are often multiple rooms that have their temperature regulated by a single steam valve. The product should be able to take preferences from each occupant to try and find the best possible valve setting.

4. **External control**: The facilities and maintenance personal need to have a method to set limits on the temperature control.
5. **Removable mechanical interface**: The mechanical interface to the valve must be able to be easily removed. To avoid plumbing complications and to simplify installation and removal the unit must interface with the current valve knob with minimal alterations to existing infrastructure.
6. **Network interface**: The unit will have a network interface that will be able to communicate over the internet. The interface shall be able to configure the controller from a remote computer terminal.

Non-Functional Requirements

We did not receive non-functional requirements from our client. From experience with HVAC controllers, our group has a fundamental understanding of product usability and the importance of aesthetics in a successful product. With this in mind, our group has drafted non-functional requirements that will allow us to design a successful product. The portion that we will consider is the user interface unit. The following lists these requirements in no particular order:

1. Large LCD in order to improve visibility for users.
2. Graphical based LCD in order to ease usability and decrease the need for text based commands.
3. Gray, green, yellow, or blue tint of LCD to increase aesthetic appeal.
4. Large rubber base push buttons in order to ease usability.
5. Translucent push buttons to add aesthetic appeal.
6. Neutral color of user interface casing – white, off white, or gray to offset from the push buttons and LCD.

Design Constraints

1. **Minimum alteration to existing infrastructure**: The facilities planning and management would like the existing infrastructure to remain as unaltered as possible in order to preserve the integrity of the existing steam pipes. Minimum alterations of the valve knob are allowable.
2. **Limited heat output:** The controller of our design is limited by the heat output of the current steam heat distribution systems. This severely limits the ability of our controller to quickly adjust the temperature in the room.
3. **User rationality:** The extended response time of the system may also lead to irrational use by the user. The user may increase the temperature prematurely in an attempt to arrive at the desired temperature.
4. **Limited testing period:** The steam heating system is only active during the winter months. This limits our functional testing to the early spring semester.

Technical Approach Considerations and Results

Each component of the two sub-systems must be selected according to certain technical specifications and considerations. Both subsystems require a wireless transceiver and microcontroller. The other major components for the controller box include an electric motor and network interface adapter. The other major components for the control panel include the LCD display and temperature sensor.

Wireless transceiver: The wireless transceiver is used to communicate between the controller box and the control panel. A mesh networking structure is used to allow each of the control panels to communicate with the controller box and with each other in an effort to extend the range of the system. Use of the existing Wi-Fi wireless network was considered. However the mesh network architecture eliminates any need for a separate wireless network infrastructure and is considerably more affordable. Other technologies were considered, including wi-fi.

Figure 5: Xbee Wireless Transceiver

A standard n network interface is 2-4 times the price of the chosen mesh network protocol, the IEEE 802.15.4 standard. This standard was chosen to ensure compatibility with the largest number of products. Although there are products with proprietary technology that expand the functionality of the wireless transceiver, the standard protocol was elected. The Xbee product by Digi has been selected as a product that meets all of our requirements, including the ease with which it can be integrated with the microcontroller using a simple serial interface, the affordability and the flexibility provided.

Other benefits of using the selected technology include low power consumption that would allow for extended battery life. It also includes the ease of expansion or reduction of the size of the system to adjust to the number of rooms connected to a single steam valve. It also has provisions for reliable packet delivery, such as retrying missed packets and acknowledgement of packets received. However the system has a very limited data rate of only 250 kbps. Although this is significantly lower than other wireless solutions such as wi-fi, this is more throughput than we will need in order to transmit basic temperature data and intermittent status messages.

Microcontroller: A microcontroller is needed to provide the control logic for both the controller box and the control panel. The microcontroller selection was based on its capabilities, its cost, and the level of programming difficulty. Using these considerations, our group has selected two different microcontrollers to choose from each capable of controlling and processing information from each of the devices. The following breaks up the capabilities needed for our products to function.

Figure 6: Microcontroller

We will be using one microcontroller to implement the functionality of the controller box as well as the user interface. Through this approach, we can save money by purchasing in bulk. The user interface unit will require a microcontroller with one SPI for the LCD interface, one ADC for the temperature sensor, a UART for the wireless communication, and 5 general purpose input output pins for the 3 push buttons, one speaker, and one potential motion detector. This microcontroller needs to operate on 3.3 V technology or better.

The steam valve controller unit will need to have one USART for the wireless communication, Ethernet port capability, PWM for the motor driver circuitry, and 3 GPIOs for a shaft encoder and a speaker. This microcontroller needs to operate on 3.3 V technology or better. Since this unit will be close to the steam pipes, the microcontroller will need to operate at around 100 degree Fahrenheit temperatures.

Given the above features and capabilities, our group has selected three microcontrollers. The first microcontroller that our group selected is produced by Atmel, model number AT32UC3A0128. There are a few benefits to using this microcontroller. This particular microcontroller has 128 KB of programming memory and operates on 3.3 V technology. It has an USB interface, an Ethernet interface, one seven channel PWM, four USARTs, two SPIs, one Analog-To-Digital converter, and an 16 bit Stereo Audio Bit stream. It meets all of our functional requirements. Also, this microcontroller has large software support libraries online that will help with overall programming. Because Iowa State University uses many Atmel products to teach students about engineering, we can save money by using the existing debuggers and compilers. However, there is a drawback to using this microcontroller. It has 144 pins and we will be using 50 to 60 % of these pins. It wastes some of the functionality but provides freedom to expand on the project during the design process without too much difficulty. Also, because it is a bigger unit, it draws more power than the average microcontroller. Nevertheless, the price is reasonable at 10 dollars per unit.

The other microcontroller that our group selected is produced by NXP Semiconductor, part number LPC1963FBD100, 551. There are also a few benefits to using this microcontroller. This particular microcontroller has 512 KB of programming memory and operates on 3.3 V technology. It has an USB interface, an Ethernet interface, one PWM, four UARTs, CAN, two I2C, one SPI, one Analog-To-Digital converter, and one Digital to Analog converter. It meets all of our functional requirements. Also, this unit has a smaller pin out of 100 pins and consumes less energy. We would use approximately 80 percent of the pins and functionality of this microcontroller. However, there are a few drawbacks to using this microcontroller. This microcontroller does not have large software support libraries online and will take a very long time to program. Because Iowa State University does not use many NXT Semiconductor products to teach students about engineering, we will have to purchase debuggers and compilers. Nevertheless, the price is reasonable at 7 dollars per unit.

Our group has decided to use the Atmel microcontroller. The reason that we decided to use this unit was strongly supported by the fact that it has a large software support library online. Even though we might be wasting functionality, we will have a lot of freedom to design and expand our system functionality in the long run. The microcontroller capabilities and functionality meets our needs for both systems. Since we will not be using some of the pins, the power consumption will be halved as that indicated on the datasheet.

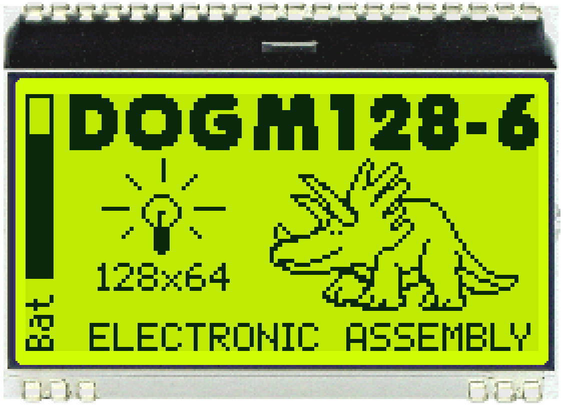


Figure 7: LCD Display

LCD display: The LCD is used as an aid for our human machine interface -to communicate between the controller box and the individual. Several different LCD technologies have been considered. Our group researched LCD numeric, character, and graphic display modules. The LCD numeric display modules are extremely low power units, easy to configure, and relatively inexpensive. However, they are not user friendly, do not have a back light, and are limited to displaying only numbers. The LCD character display modules are modules are low power units, moderately simple to configure, are relatively inexpensive ~ 10 to 15 dollars, and have a back light. However, they are not user friendly, and are limited to displaying only characters. The LCD graphic display modules are modules are low power units, are moderately inexpensive ~ 20 to 22 dollars, are user friendly, have a back light, and are not limited in terms of display. However, they are moderately difficult to configure in terms of software development.

After a group discussion, we decided to use an LCD graphic display module. A super twisted pneumatic LCD was chosen in order to achieve a high contrast ratio and reduce back light intensity, thus reducing power consumption. We chose to use the DOGM128-6 Electronic Assembly family of LCDs because they have low power consumption and they offer more flexibility in graphics programming and tools to help ease the programming process. The DOGM128-6 family includes an integrated LCD driver and uses the SPI communication protocol, allowing for easy integration with a variety of microprocessors.

Another factor in our decision was the size of the display. Many of our users are weary students and faculty members. We needed an LCD that allowed for large easy to use text and graphics. Most of our electrical components function on 3.3 V technologies. The DOGM128-6 was one of the few LCDs with an appropriate size with a capacity to function with 3.3 V. Our group had to find a display that would be able to operate under varying temperature conditions. This particular LCD met our standards for operating temperature range between -20 degrees Celsius and 70 degrees Celsius.

The final consideration was availability. According to Mouser Electronics, this is one of the most widely available LCDs with a large stock. Given the size, quality, and availability, the estimated LCD cost is around 15 dollars. The DOGM128-6 family has LCDs that range from 4 to 18 dollars based on various backlighting and color schemes. This allows us to create an extremely flexible and cost effective product.

Power Supply: The power supply is used to power both the controller box as well as the user interface unit. Several different power supply technologies and designs were considered in our group's design process. The main portion of the design will consist of a AC/DC converter that steps the voltage from 120 V 60 Hz down to 12 V DC. The rest of the design will consist of the common circuit chip sets including a switcher to convert 12 V to 5 V and an LDO to drop from 5 V to 3 V. In determining the power supply technology selection, our group considered several different options.

Figure 8: Power supply transformer

Our first option was to purchase a 120 V 60 Hz to 12 V DC wall adapter and use electronic components to route and regulate the appropriate power sections of the board. Through this approach, we will already have a fairly clean 12 V DC to use to power the board. We will not have to implement any other complex circuitry. In selecting the adapter, we can select the appropriate power ratings to accommodate our system. These adapters are fairly inexpensive and are easy to implement, saving costs on expensive circuit components.

Our second approach was to purchase a 120 V 60 Hz to 20 V AC wall adapter and use a buck converter to create a stable 12 V signal to power the system. Through this approach, our team could save around 6 to 8 dollars on the adapter. However, there are a few detriments to this approach. The main component in our system is a high power motor that has the potential to draw 2 A. Due to this fact, we would lose money designing the buck converter due to expensive high power rated components. Also, the signal that we would achieve might not be as clean as the AD/DC 12 V signal.

Our third approach was to purchase an outlet plug in and design the circuitry to convert from 120 V 60 Hz to 12 V DC. There are several issues with this approach. Because our system has the potential to draw a large amount of current, the components used would have to be large and have large power ratings. It would increase the area of the PCB design by at least half the amount. This portion of circuitry would also give off a lot of heat and would require heat sinks and might become a fire hazard given that it will operate around a fairly hot steam valve. The only benefit of this system approach would be a cost savings of approximately 10 dollars.

After discussing with the group members, we have decided to implement the 120 V 60 Hz to 12 V DC power system because of all of the benefits. Through this approach, we will save money because we will not require any extra components to perform AC to DC conversion. We will also save PCB area by removing much of the bulky power section. This will increase the size of the outlet plug but will allow for a better quality of signal. Through this approach, we will already have a fairly clean 12 V DC to use to power the board. Because we will purchase the adapter, we have freedom to select the appropriate power ratings to accommodate our system. These adapters are fairly inexpensive -20 dollars- and are easy to implement. This approach is slightly more expensive – 5 dollars – but will increases the quality of our design by allowing for a more reliable system.

NiMH Charger: The NiMH charger is used to re-charge the power supply of the user interface, two AA batteries in series. Several different NiMH charger technologies were considered in our group's design process. The first is a common integrated recharging circuit called the bq2002C. It has very fast charging capabilities, it has direct LED outputs to display charging status, it has charge termination by voltage, temperature, and time, it is a low power unit, and it is relatively inexpensive, about 2 dollars. The only detriment to this technology is that the unit will not indicate when the batteries are low. Another popular NiMH charging technology that we considered is the bq24401 charging unit. It has very fast charging capabilities, it has direct LED outputs to display charging status, it has charge termination by voltage, temperature, and time, it is a low power unit, and it has a safety check implementation that can check for damaged battery units. However, this technology also has a few detriments. The unit will not indicate when the batteries are low, it costs around 4 dollars, and it needs to be programmed.

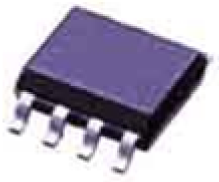


Figure 9: Battery charger

After much discussion, our group chose to use the bq2002C because it is half the price of the bq24401 and it does not require programming. We did not want to spend more of our client's money on programmers. The bq2002C has all of the technology and capabilities that we need to perform a battery charge. Given that it cannot detect a low battery voltage, we will have to incorporate a solution in our design that tells the individual when to use the charger.

Temperature sensor: The temperature sensor is a mandatory component for the Steam Heat Controller prototype design. Below are some of the technical selection qualifications for the temperatures sensor:

1. The team has decided that the temperature sensor should not be embedded on the microcontroller. This will reduce the maintenance cost since the entire microcontroller will need to be replaced if a malfunction or damage occurs to the embedded temperature sensor. By using an independent temperature sensor also eliminates possible reading errors caused by the heat produced by the microcontroller or other components for the prototype.
2. The team has decided to use a temperature sensor with a voltage output over digital output. Price is an important factor that needs to be considered when dealing with the temperature sensor. Even though temperature sensors with digital output type have wider sensing temperature range and more accuracy, its price compared to a temperature sensor with voltage output is significantly higher.

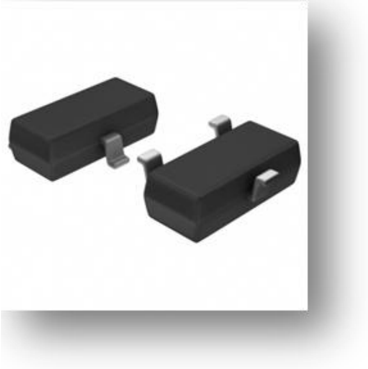


Figure 10: Temperature Sensor

Functional Requirements

The functional requirement for the temperature sensor is as follows: be able to accurately measure the temperatures for the steam heat controlled rooms within plus or minus two Fahrenheit.

Design Constraints

- **Temperature range**: 32 degrees Fahrenheit to 100 degrees Fahrenheit. This range is the potential temperature within a steam heat controlled room.
- **Accuracy**: within ±2 degrees Fahrenheit of the real temperature
- **Reliability**: popular user ratings (over 2500 users)
- **Availability**: readily available from its distributors (20,000 units in stock)
- **Price**: $1-$2

Mechanical System: There are two distinct systems that need to be analyzed and evaluated: the stationary platform and gear motor system.

Stationary platform technical approach considerations and results

Due to limitation of our team's mechanical aptitude and experiences, we worked with our clients to develop the stationary platform to house the controller box on top of the steam valve. In assessing the physical constraints surrounding the steam valve, we identified the following characteristics that were required of our stationary platform.

- Clamps will be needed to attach the stationary platform to the steam pipes. This will ensure easy attachment and detachment of the whole controller box unit.
- Extrusion aluminum will be used to form the skeleton of the stationary platform. Our clients requested the extrusion aluminum since their expertise and experience have been developed using this material.
- The mounting plate for holding the gear motor will position the gear motor vertically on top of the steam valve. This configuration will reduce additional work on implementing 90 degree angle connection between the gear motor and the steam valve. The resulting implication would be that our selection of the gear motor will be limited to gear motors that allow face mount configuration.
- The front side of the finished stationary platform should allow modifications to allow mounting the controller box unit. Dude to the space constraint that the steam valve has on its backside, sides, and top, we determined that placing the controller box unit attached to the front of the stationary platform would provide flexibility for the whole unit to address different placement of the steam valve across the Coover building.

These observations were made by viewing the current steam valve placement in room 1307 of Coover. The following images were taken from that room.

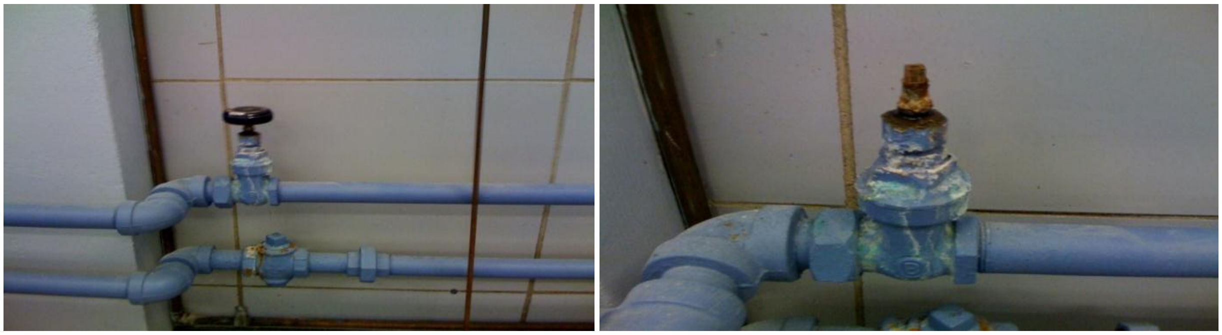


Figure 11: Current Steam Valve System

With these constraints and characteristics, we worked with our clients to craft the detailed design of the final stationary platform.

Gear motor system technical approach considerations and results

The gear motor system consists of three parts: the gear motor, the shaft encoder, and the motor driver IC.

Gear motor

During our research and selection of an appropriate gear motor, we developed the following selection requirements for the gear motor.

Electric Motor	
Type of motor	DC
Operating Supply Voltage	12-24V
Torque	0.95 N m
Speed	6 rpm
Availability	5-10 years out
Functionality	CMOS/TTL compatible shaft encoder
Safety	shaft encoder & motor driver circuit
Cost	prioritize functionalities over low cost

Figure 12: Electric Motor considerations

In addition to these requirements, we had three alternative solutions for resolving our functionality need in requiring a shaft encoder. These three alternative solutions include:

Gear motor with custom shaft encoder

We would design a custom shaft encoder to complement a gear motor that lacked an integrated shaft encoder. Our approach would be to attach a saw tooth belt that would connect the shaft of the gear motor with an external shaft encoder.

The advantages of this approach include increased variety of gear motor selection, potential lower cost for selecting a shaft encoder, and availability of both gear motor and shaft encoder would remain stable for the coming years.

The disadvantages in using this approach include increase opportunities for mechanical failure due to additional work to integrate the gear motor and custom shaft encoder. Other disadvantages include increased complexity for maintain and repair, having two separate units would make it more difficult to attach or detach the units. Lastly, the time required to research, plan, implement, and evaluate the combination would endanger our project schedule.

Gear motor with attachable shaft encoder

We would purchase a gear motor capable of having an attachable shaft encoder. The addition requirement of this approach would be selecting a gear motor with a back side shaft that an external shaft encoder could fit onto.

The advantages of this approach would be a simpler integration of gear motor and attachable shaft encoder, easier maintenance and reparability of the individual units, and provide possible upgrade of either gear motor or shaft encoder.

The disadvantages of this approach include limited variety of gear motor with exposed back shaft for attachable shaft encoder, potentially higher cost, and limited variety of attach shaft encoder. Our initial research for this approach suggested low variety in component selection and would endanger the capability of our solution.

Gear motor with integrated shaft encoder

This approach requires purchasing a gear motor that has an integrated shaft encoder. The manufacturer of the gear motor would be responsible for integrating the functionality of the shaft encoder and ensuring the mechanical stability of the integrated product.

The advantages in using this approach include purchasing an integrated solution that would allow us to bypass mechanical work, simplification of our design, time savings, and lower cost savings.

The disadvantages in using the approach include limited variety of gear motors with integrated shaft encoder and high cost of replacement should one part of the integrated product fail. The initial research in the approach revealed limited selection of capable gear motors. However, the potential time savings and reduce integration complexity pushed us to consider this approach.

Selected approach

Comparing the three approaches for designing the gear motor with shaft encoder capabilities, we decided to go with the integrated solution approach. We were aware of the limited variety of selection and high cost of replacement. However, the potential time savings, cost savings, and reduced design complexity were critical advantages we needed to maintain our schedule and budget.

We were also attracted to the integrated from our testing of an available gear motor with integrated shaft encoder. The integrated solution sped up our software testing in controlling the motor and simplified the necessary circuitries.

Once we selected our technical approach to the gear motor, we had to identify the requirements for the performance of the shaft encoder.

Shaft encoder

From our chosen approach for a gear motor with integrate shaft encoder, we were now primarily concern with accuracy and technology of the integrate shaft encoder.

Shaft encoder accuracy

Upon discussion with our clients about the accuracy of the steam valve rotation, they want to see an accuracy of ± 5 degrees. The constraint will limit the selection in our search for the gear motor with integrated shaft encoder.

Shaft encoder technology

When looking at the available shaft encoder technologies, we identified two prevalent approaches: optical and magnetic.

Optical shaft encoder

Optical shaft encoders are lower cost, provide higher resolution, and are the dominant technology used in shaft encoders. However, Optical shaft encoders are prone to seal failures, mechanical shattering, and bearing failures.

Magnetic shaft encoder

Magnetic shaft encoders are less prone to seal failures and shattering. However, higher cost and lower resolution are disadvantages of using magnetic shaft encoder.

Our analysis of the two shaft encoder technology concluded that reliability is higher priority than cost and resolution. Therefore, we decided to pursue a magnetic shaft encoder to accompany our gear motor.

Once we defined the necessary shaft encoder accuracy requirement and agreed upon using magnetic shaft encoder, we proceeded to define our approach for the motor driver IC.

Motor driver IC

During our research and selection of an appropriate motor driver IC, we developed the following selection requirements, some of which were dependent upon the gear motor specification.

Motor Driver IC	
Operating Supply Voltage	dependent on selected gear motor
Accepted Input Standard	CMOS/TTL
Current Output	dependent on selected gear motor
Availability	5-10 years out
Safety	over current protection & over temperature protection
Cost	prioritize functionalities over low cost

Figure 13: Motor Driver IC considerations

With these initial requirements, we identified two groups of motor driver IC that are available on the market: application specific and general application.

Application specific

Under the application specific group, we observed functionalities and features that were specific to motor control. These ICs are well designed and documented for motor control.

The advantages of this approach include specialized enhancements designed for motor control, higher quality to handle extreme environments, and appropriate documentation on implementing motor control.

The disadvantages of this approach include high cost, over performance, and limited variety of selection.

General application

Under the general application group, we observed available ICs that had functionalities that would be modified to implement motor control. The ICs are designed for a multitude of application, but lack proper documentation for motor control.

The advantages of this approach include low cost, high variety of selection, and flexibility of implementation.

The disadvantages of this approach include limited operating environment when compared to application specific and additional design necessary to implement motor control.

Selected approach

Evaluating the two groups of available ICs for motor control implementation, we discussed our reasons for selecting ICs available under general application with our clients. General application ICs deliver the best cost effective while providing appropriate performance and functionalities. We confirmed with our clients that there were available ICs that could easily provide motor control and at low cost.

Once we had selected the approaches for the gear motor and motor driver IC, we proceeding to identify the final components selection and confirmed their ability to meet our design needs.

Control algorithm: The control algorithm used to control the valve is a PID feedback control algorithm as outlined in figure 10. This algorithm uses feedback to control the heat output of the heating system and regulate the output according to the set point. This feedback is provided by the control panel's temperature sensor. The input from 3 separate temperature sensors will be used in a weighted average to provide the feedback signal. Similarly the set point will be a weighted average of each user's preference. The algorithm is a well-established standard control algorithm that is often used in industrial control processes. The PID's controller must be tuned in order to adjust the response of the system. There must also be some mechanism to simplify the tuning process. There will be a method to profile a room in order to simplify the tuning process and potentially improve the efficiency of the temperature control using the added information. The PID controller will undergo extensive testing and revision as necessary.

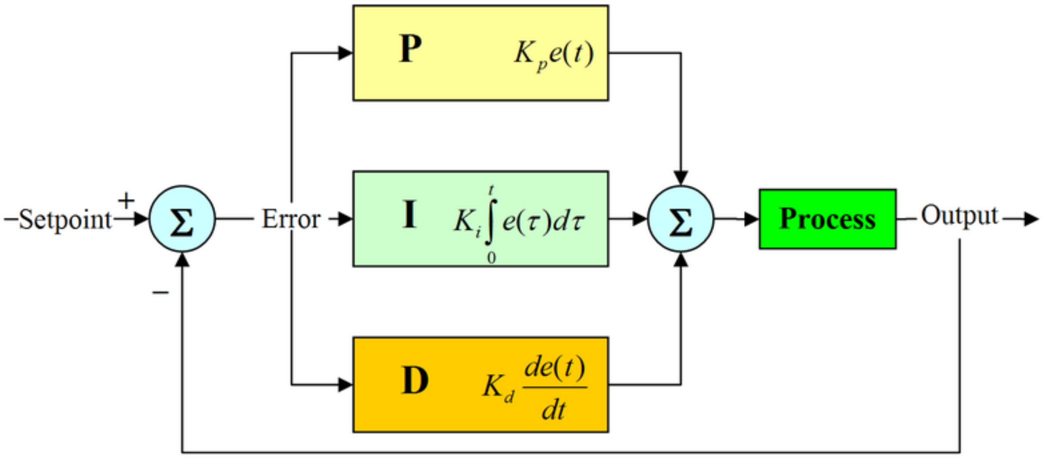


Figure 14: PID Control Algorithm

In order to calculate the set point for the controller an average of each room's preference must be taken. The set point needs to be designed as a weighted average to account for the differences between rooms.

Figure 15: Ethernet Transceiver

Ethernet Transceiver: The Ethernet transceiver is a mandatory component for the Steam Heat Controller prototype design. Below are some of the technical selection qualifications for the Ethernet transceiver:

1. The Ethernet transceiver needs to be able to easily communicate with the Steam Heat Controller's microcontroller. The microcontroller the team has picked supports both the MII and RMII interface. This means that the Ethernet transceiver needs to be able to transmit and receive data across either the MII or RMII interface.
2. The Ethernet transceiver needs to be fully compliant with the IEEE 802.3 specification, which is supported by the Steam Heat Controller's microcontroller and also the most widely used standards for the physical layer and the data link layer's media access control of wired Ethernet.

Functional Requirements

The functional requirements for the Ethernet transceiver are as follows: be able to reliably send data from the Steam Heat Controller's microcontroller to the Iowa State University's network; be able to reliably receive data from the Iowa State University's network for the Steam Heat Controller's microcontroller.

Design Constraints

- **Operational Temperature range**: The operational temperature range for the Ethernet transceiver needs to work between 32 degrees Fahrenheit and 100 degrees Fahrenheit. This range is the potential temperature within a steam heat controlled room.
- **Reliability**: popular user ratings (over 2500 users)

- **Availability**: readily available from its distributors (5,000 units in stock)
- **Price**: $2-$5

Website Interface: The website interface is a mandatory component for the Steam Heat Controller prototype design. Below are some of the technical selection qualifications for the website interface:

1. The website interface backend should support the platform given by the Iowa State University, which could be either Windows or Linux based server environments
2. The website interface can be done using either PHP and or Java. The advantage for both are that they are free technologies and readily available for download on the web and both contains full API support. Java is more scalable than PHP and can use JDBC to talk with MySQL database while PHP is more widely used in for web development. PHP will be used for web authentication while Java/JDBC will be used to interact with MySQL database.
3. Apache, MySQL, or Tomcat will be used for storing data from received from the Steam Heat Controller. MySQL will be used since one team member already has knowledge about MySQL thus reduces the learning curve.

Functional Requirements

The functional requirements for the website interface are as follows: be able to reliably and securely read data from the Steam Heat Controller; to be able to reliably and securely send data to the Steam Heat Controller for adjusting the steam heat valve; to be able analyze data sent from the Steam Heat Controller; to be able to have secure login for admin and users; to be able to take user input for temperature preferences.

Design Constraints

- **Server availability:** need to use the server provided by Iowa State University
- **Server space:** the limit for the server space will be capped at 1000 MB
- **Network security**: needs to securely transmit and receive data from and to the Steam Heat Controller

Testing Approach Considerations

Testing requirements considerations

Our testing approach will be broken into two phases. In the first phase each of the components will be tested individually to ensure they meet their own individual requirements. This phase will also assist in developing our understanding of each component. After this phase our integration plan may need to be altered as we understand each component's functionality better. Then in the second phase the entire integrated system will be tested including functional and non-functional tests. This will have to take place during the winter months and will be a vital link in the success of the project. A PID (Proportional Integral Derivative) feedback control algorithm will used to actually control the temperature of the rooms by adjusting the steam valve. This type of controller will require significant adjustments to the controller's parameters (coefficients) for the controller to be effective.

Phase 1 testing requirements and procedures for each component are outlined below:

Wireless transceiver: There are a number of tests that must be performed. The unit must be tested to ensure basic functionality, range, and reliability. The most basic test would be to test basic functionality to ensure the unit can properly transfer data bytes. Then the transceiver's range must be tested. This must be done in the product's intended environment. A variety of environmental factors must be tested, including having a transceiver that needs to reliably communicate up to 3 rooms away. Incorporated into the range tests will be a test of reliability, with reliability being measured as the percentage of the transmitted bytes that were received by each transceiver as a function of the range.

LCD display: There is a multitude of tests that must be performed. The first tests to be performed should ensure basic functionality and reliability. The most basic test would be to test basic functionality to ensure the unit can properly display data and graphics. Then, the LCD backlight should be tested. This should be done in the product's intended environment across various lighting conditions and temperature ranges. This testing will allow us to set the appropriate contrast and brightness and allow for minimum power consumption. Pixel reliability needs to be measured in order to make sure that the LCD is displaying the transmitted data properly.

Temperature Sensor: In order to test the accuracy of the temperature sensor, the team will compare its readings with temperature readings from reliable readings (thermometer). Data recordings from both the reliable reading and the readings from the temperature sensor will be recorded overnight and analyzed for accuracy. The team will also measure the temperature sensor's accuracy at 32 degrees Fahrenheit and 100 degrees Fahrenheit

Mechanical interface: Our testing approach to implementing the mechanical system began prior to selecting the individual parts. We were fortunate enough to have on hand parts that we could test and develop the software prior to selecting our final components.

Testing prior to final component selection

With the following components available from the Ecpe resource department, we were able to write test code for mechanical functionality.

- Arduino - microcontroller
- Pittman GM9000 - gear motor
- HEDS-9100 - optical shaft encoder
- LMD18200T - motor driver IC

As a result of our early testing, we were able to learn the following objectives that would aide in testing and integrating the final selected components.

- functional code available to be ported to selected microcontroller
- experience with circuit layout for testing
- aide in selecting approaches for mechanical system

The opportunity to work with available material was helpful in deciding appropriate technologies, approaches, and requirements for the final component selection. Once we had the selected components on hand, we proceeded to test them using software coded in the initial testing.

Testing after final component selection with Arduino

With the following components, we are currently testing the components and ensuring the software coding will implement the correct mechanical functionalities.

- Arduino - microcontroller
- IG42 - gear motor
- Integrated magnetic shaft encoder
- L298N - motor driver IC

Notice that we are still using the Arduino to code for and test the functionality of the gear motor, shaft encoder, and motor driver IC. This is because we want to have a working mechanical system in place prior to January 1st of 2011 so that we could begin temperature profiling of the rooms. Since our selection of the microcontroller will be later on in the design process and complexities of the final selected microcontroller would require additional time to code for, we will use the Arduino to provide preliminary mechanical functionality while we bring up the final coding on the selected microcontroller.

We used the test circuits, available in Appendix A. With the testing, we were to confirm motor control accurate to ± 10 degrees, therefore further investigation will be need to increase accuracy of the motor control.

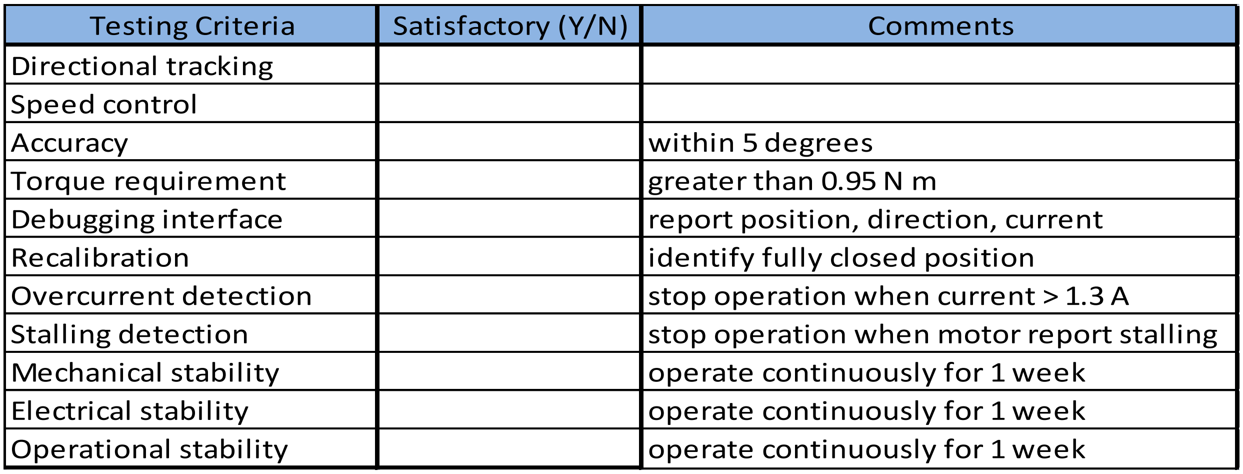
Our current progress is to improve the accuracy of the motor control while bringing up the testing using our final selected microcontroller, the Atmel U3A0128.

Testing after final component selection with that Atmel U3A0128

Testing of the selected mechanical components using the Atmel U3A0128 will employ the same test circuitry shown in Appendix A. However, we will port the Arduino code to the Atmel U3A0128 prior to mounting the mechanical in place and performing a final testing.

Exiting testing phase criteria

The criteria that need to be met before exiting the testing phase of the mechanical system include:



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

Figure 16: Mechanical interface Test criteria

The mechanical system undergoes extraneous testing due to safety implications. We want to ensure that the mechanical system will not endanger the steam valve and the Coover building as a whole. We will evaluate the final mechanical system to the testing criteria above and additional testing as we progress in its development.

Ethernet Transceiver: In order to test the functionality of the Ethernet transceiver, the team will first transmit a 1 byte data packet across the Iowa State University's network to the Steam Heat Controller. The team will verify the data integrity by displaying the data transmitted on the LCD. The team will then transmit a 1 byte data packet from the Steam Heat Controller to Iowa State's network and verify the data integrity by printing the data to the web interface. Larger size data will be used to test data integrity once the 1 byte data packet test is successful.

Website Interface: To test the website interface, the team will try to authenticate the website interface as admin and user and try to respectively set temperature preferences for the steam valve controlled rooms. The team will also be implementing series of tests to make ensure that reliability and integrity of the data received.

Microcontroller: There are a number of tests that must be performed. The unit must be tested to ensure basic functionality and reliability. The most basic test would be to test pin functionality to ensure that the units perform the appropriate functions and have good signal integrity. The voltage rails need to be tested in order to ensure low ringing on the lines. The microcontroller's operation needs to be tested at a wide range of temperatures in order to assure a reliable product. The signal communication lines need to be tested for reliability, with reliability being measured as the percentage of the transmitted bytes that were received correctly.

Control algorithm: The control algorithm must undergo extensive testing and revision in the final stages of the project. The control algorithm is a software implementation that is dependent on the hardware configuration and hence must be part of the last stages of development. However as a critical component to the success or failure of the project there must be sufficient time allocated to the testing, tuning and revision of the control algorithm.

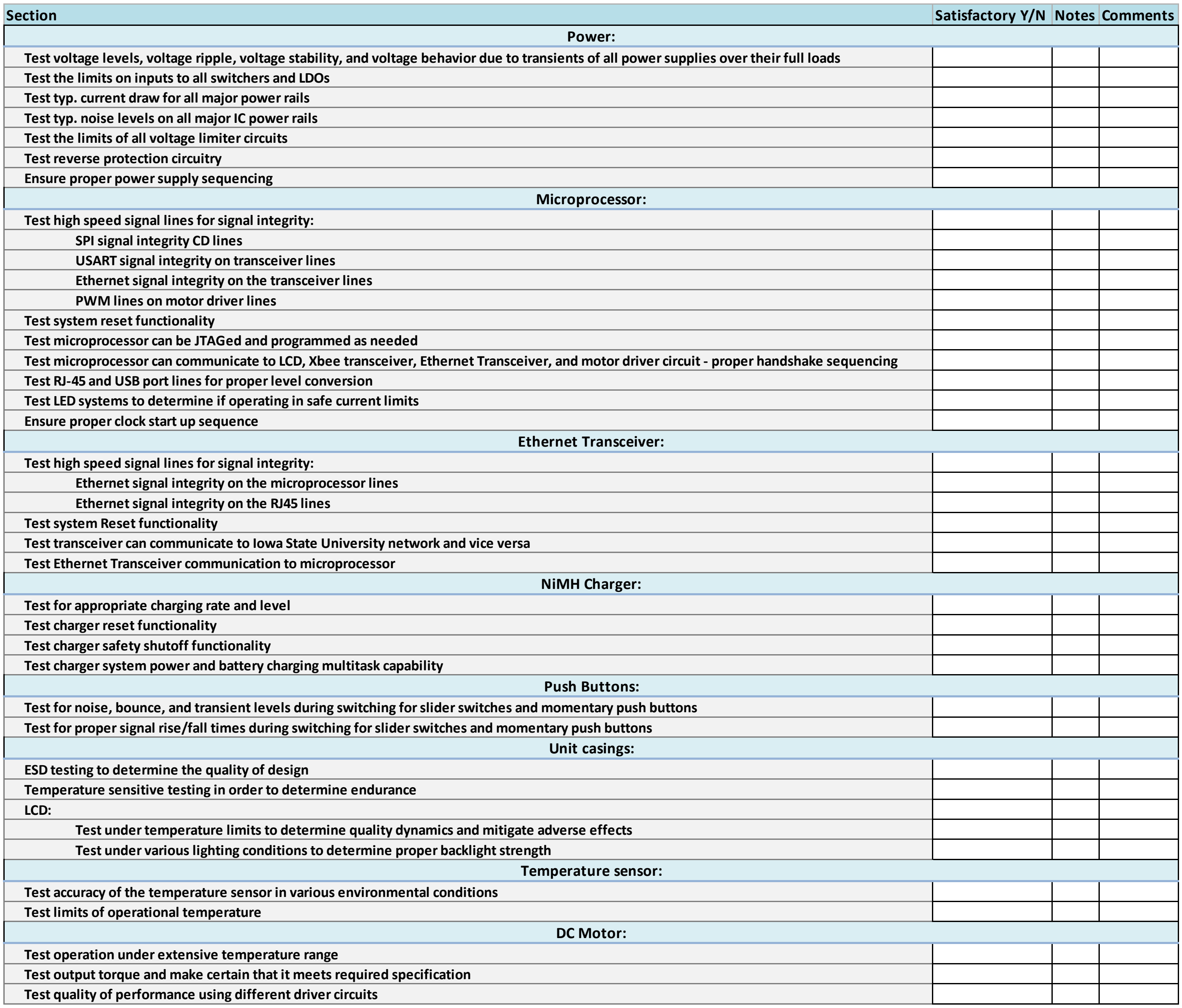
The testing of the control algorithm will need to include live testing where the system is ran and monitored over a series of tests under different environmental standards and operating conditions. Testing will begin with a single room that is controlled using a single control panel and controller box. The testing will then be expanded to include multiple rooms with multiple user interfaces.

Temperature Sensor: In order to test the accuracy of the temperature sensor, the team will compare its readings with temperature readings from reliable readings (thermometer). Data recordings from both the reliable reading and the readings from the temperature sensor will be recorded overnight and analyzed for accuracy. The team will also measure the temperature sensor's accuracy at 32 degrees Fahrenheit and 100 degrees Fahrenheit

Phase 2 The phase two tests are divided into three main categories, hardware, software and functional testing. The testing requirements and procedures for each component are outlined below:

Hardware Testing Approach Considerations:

The hardware will be tested upon receiving and populating the first prototype of the PCB board. It will be tested in the senior design lab using standard bench equipment such as the oscilloscope, multimeter, and power supplies. The following portions of hardware will be tested along with particular subsections indication the appropriate tests involved:



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			

Figure 17: Hardware test plan and criteria

Testing will be accurately determined through thorough implementation and careful observation of system behavior. Upon completing a test, the results will be documented along with information pertaining to whether further action needs to be performed in order to fix that particular portion of the system. Benjamin Jusufovic and Curtis Mayberry will perform the hardware testing. One will test a section and the other will verify the results through another implementation of the procedures.

Software Testing

LCD, Temperature, and Microcontroller

Test Case	Pass	Fail	Comments
1. Display all characters supported by the LCD			
2. Verify correct display results for all components			
a. Correctly displays current temperature readings			
b. Warning for low battery			

3. LCD display updates accordingly after user input			
4. LCD displays desired output after system reboot			

Ethernet Components

Test Case	Pass	Fail	Comments
1. Receive buffer manager write of 1 byte data			
2. Receive buffer manager read of 1 byte data			
3. Transmit data DMA read of 1 byte data			
4. Receive data DMA write of 1 byte data			
5. Transmit buffer manager read of 1 byte data			
6. Transmit buffer manager write			

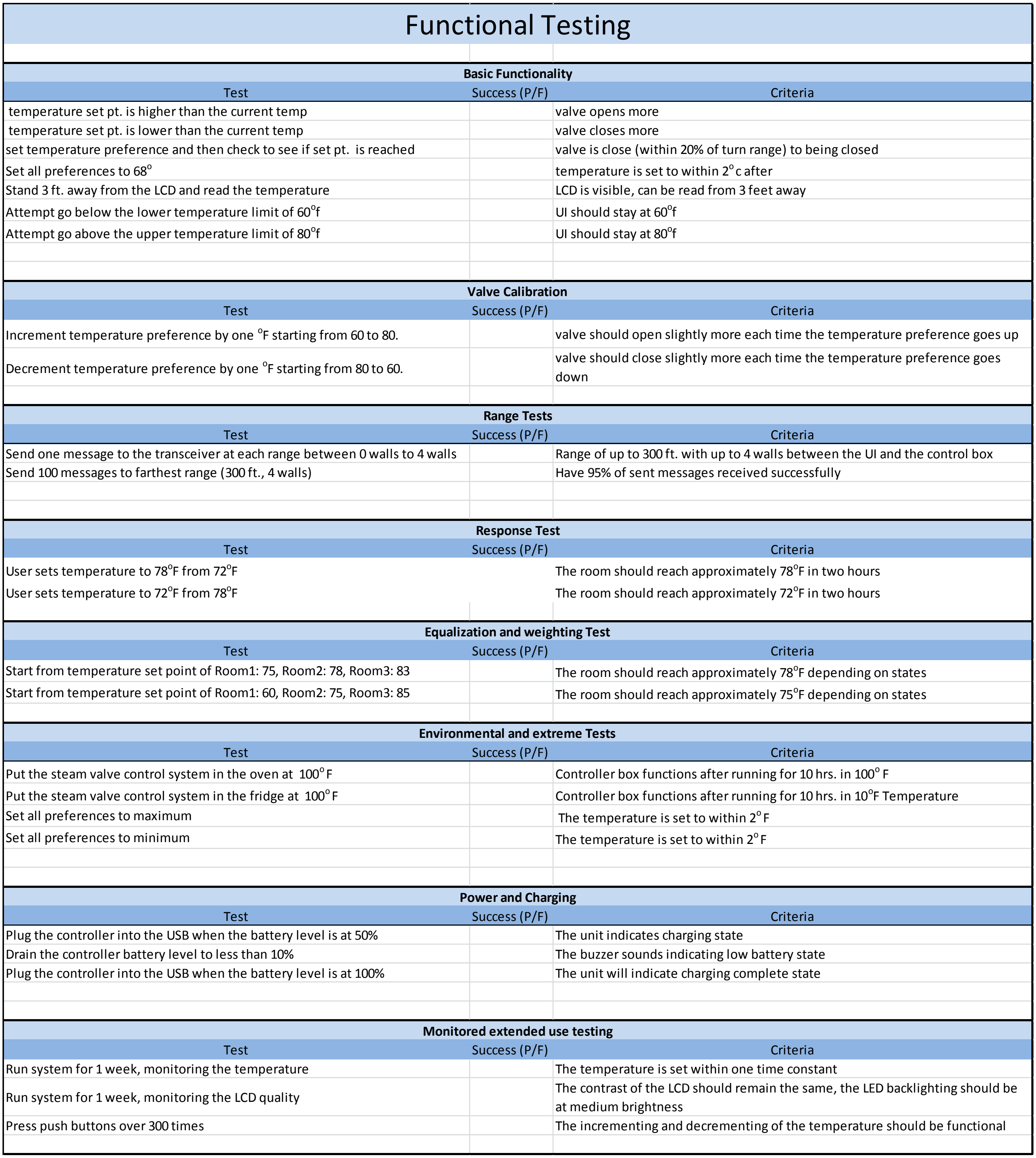
Website Interface

Test Case	Pass	Fail	Comments
1. Password authentication for average user			
2. Password authentication for admin			
3. Administrator’s ability to add, remove, or modify user			
4. Administrator’s ability to overwrite temperature preferences			
5. Verify that JDBC correctly communicates with database			
6. Web interface correctly displays the correct temperature for all rooms			
7. Verify that web interface correctly communicates with the steam valve microcontroller			
8. Verify that the user request is processed and sent to the steam valve microcontroller			
9. The status of the overall system is displayed correctly			
10. The user feedback is archived displayed for the admin			
11. The web interface correctly displays the data interpretation from the data collected from the microcontroller			
12. The database correctly stores the data sent from the microcontroller			
13. The web interface correctly retrieves data after system failure			
14. The web interface displays appropriate message after invalid user requests			

Figure 18: Software testing plan and criteria

Functional Testing

The functional testing plan was developed to test the system as a whole. A great variety of tests were developed in order to verify the functionality of the unit. The test results of the system provide final verification of the project’s success.



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°		temperature is set to within 2° c 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°f		UI should stay at 60°f
Attempt go above the upper temperature limit of 80°f		UI should stay at 80°f

Valve Calibration

Test	Success (P/F)	Criteria
Increment temperature preference by one °F starting from 60 to 80.		valve should open slightly more each time the temperature preference goes up
Decrement temperature preference by one °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°F from 72°F		The room should reach approximately 78°F in two hours
User sets temperature to 72°F from 78°F		The room should reach approximately 72°F 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°F depending on states
Start from temperature set point of Room1: 60, Room2: 75, Room3: 85		The room should reach approximately 75°F depending on states

Environmental and extreme Tests

Test	Success (P/F)	Criteria
Put the steam valve control system in the oven at 100° F		Controller box functions after running for 10 hrs. in 100° F
Put the steam valve control system in the fridge at 100° F		Controller box functions after running for 10 hrs. in 10°F Temperature
Set all preferences to maximum		The temperature is set to within 2° F
Set all preferences to minimum		The temperature is set to within 2° F

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

Figure 19: Functional test plan and criteria

Security considerations

The major security considerations to be addressed are the wireless interface and the web interface. Both of these are vulnerable to attack by outside sources. Below are the security considerations for each:

Network interface: There are two main security vulnerabilities in the network interface. First, the traffic going from the internet interface to the Iowa State network might be prone to attacks. Anyone from the room will have access to the physical Ethernet connection interface connecting to the Iowa State network and alter the data sent to the web or instructions send from the web. A possible solution is to lock the Ethernet connection between the microcontroller and Iowa State network from the users in the room.

The wireless traffic might be prone to attacks. The data broadcasted uses a common protocol and can be easily picked up by surrounding devices using snipping programs. This gives attackers the ability to perform attacks to the network interface using false authentication and change the temperature of the room. A possible solution is to encrypt data being broadcasted, and create an authentication password.

Wireless transceiver: The Xbee includes built-in security features. These security features include the addressing method used by the transceiver. There are over 65,000 unique addresses that can be set for each transceiver. The source and destination of each message is addressed. The system also has the ability to encrypt the sent data using 128-bit AES (Advanced Encryption Standard). This will help secure information sent over the wireless serial link between the control panel and the controller box. Even though the Xbee does an excellent job of securing data when configured properly, the system is designed so that the data being transmitted wirelessly is not very sensitive to intrusion. The two pieces of data that will be sent though the transmitter are the current temperature of the room to be used to complete the feedback loop of the control algorithm and the user's preference.

Safety considerations

Safety is always a major concern for any product. Our system has safety concerns related to a number of components:

LCD: The LCD consists of a glass plate structure. It needs to be properly insulated from the casing of the user interface unit in order to assure minimal stress and decrease the possibility of shatter. On the two sides of the LCD, protective plastic coverings are placed in order to protect against damage during shipping. These must be removed prior to design integration in order to the chance of reduce circuit malfunction and overheating.

Mechanical implementation: Safety is a real concern for the mechanical implementation. Our clients are concern about fire hazards should there be any malfunctions with the motor. One method to reduce this safety concern is by use of the shaft encoder. Because the shaft encoder relays information about the movement of the motor, any unresponsive movement from the motor after issuing a movement command would indicate failure in the motor. This will prevent burn out of the motor and in turn decrease the potential for fire hazards.

The other method of reducing potential fire hazards is to choose an accompanying motor driver circuit with over current protection or over temperature protection, preventing burn out of the motor. Our clients are actively concern about the safety of the product and are willing to spend additional funding to provide both solutions. We are required to have a shaft encoder to use with the DC motor and a motor driver circuit with over current protection and over temperature protection.

Driver Circuit: The driver circuit will be critical in providing the safety mechanism for the DC motor. The over temperature protection available in some driver circuits would be a plus in ensuring our DC motor avoids burn out. Over current protection will be in addition to the over temperature protection and provide further mitigation of burn out events. We will try to find a motor driver circuit that provides both features.

Temperature sensor: The Temperature sensor could malfunction due to incorrect reading or broken sensor. This can lead to huge room temperature fluctuations, which can cause extreme heating or cooling. Possible solutions to this issue are to set a low and high boundary for the motor control unit (15 degrees Celsius to 30 degrees Celsius). Another solution is to have a secondary temperature sensor that would become primary temperature sensor once an error is detected

Microcontroller: The only safety consideration is microprocessor overheating. If the microprocessor becomes too hot, it may burn individuals, cause damage to the unit, and even cause a fire. This can be avoided by smart design. Our group is experienced enough with hardware to design around these issues. We will pay great attention to detail and follow through with the manufacturer recommendations.

Recommendations Regarding Project Continuation or Modification

We recommend continuing our project as planned. Our current approach satisfies both the functional and nonfunctional requirements of the project. The estimated cost of the system has remained reasonable and the development costs have remained within budget. The team is on schedule and implementation efforts have begun. Further development efforts are planned for winter break in order to prepare the prototype for testing during the winter months.

Detailed Design

Control algorithm

The PID control algorithm has a number of components. The main component is a standard PID controller that takes in one set point and gives an output that will be read by the DC motor control logic for a PWM signal to be generated. However, since the controller must support multiple rooms, there is also an averaging and logic algorithm for both the temperature sensor feedback and calculating the set point. The temperature sensor feedback is a simple average of the input temperatures. This is illustrated in the figure below:

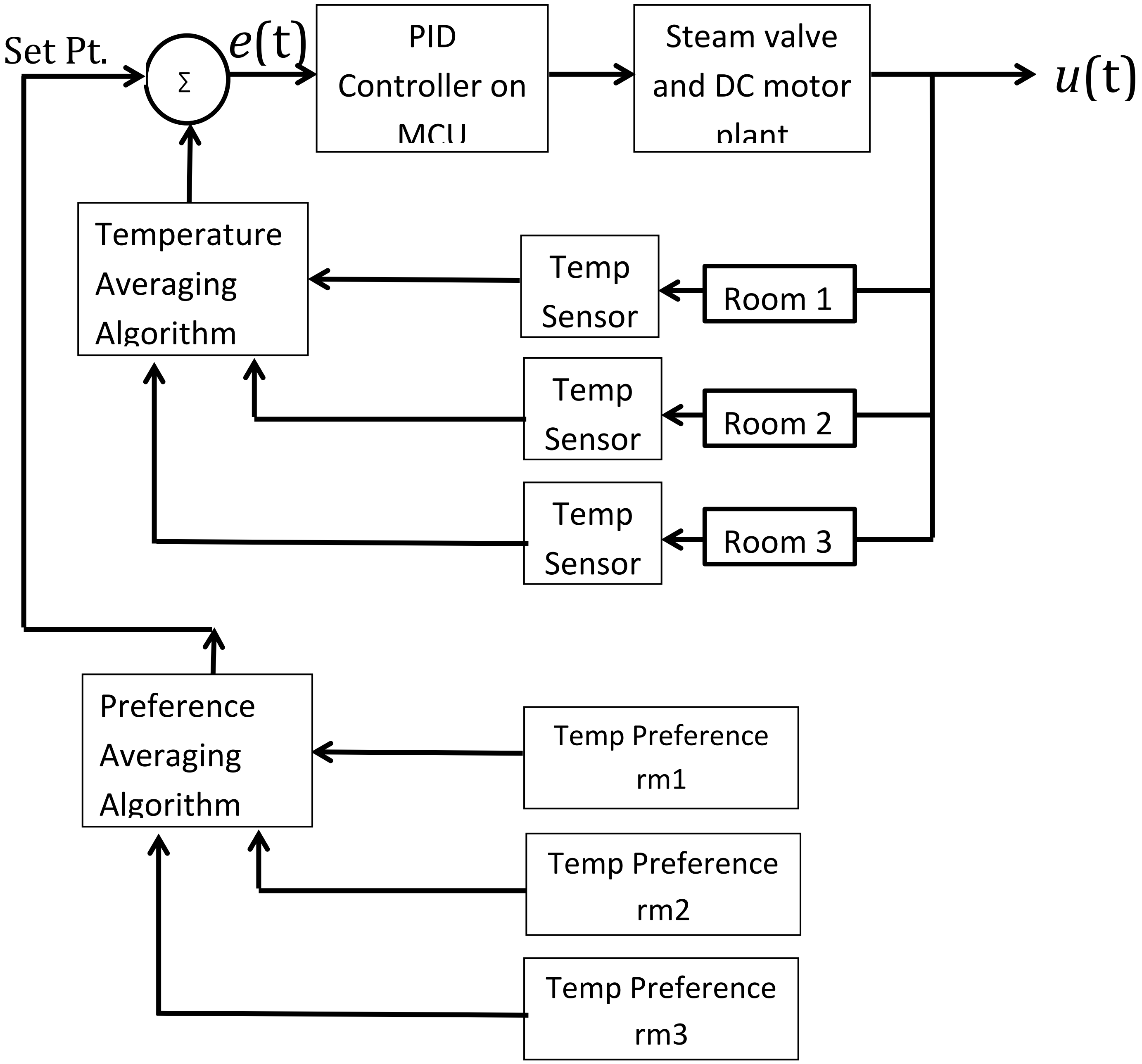


Figure 20: Controller Design

The PID control algorithm must be transformed from a continuous to a discrete algorithm in order to implement it on the microcontroller. The discrete transformation used was the Euler's approximation, which was chosen over the Tustin or bilinear transformation for its relative simplicity. The transfer function of the algorithm is given as shown in figure x, along with the difference equation that will be used to implement the algorithm in software.

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

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

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

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

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

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

Figure 21: Controller Difference Equation

Set Point Algorithm

Approach 1

In this first approach, we make the assumption that the user will always enter a temperature between 60 and 80 degrees. We can ensure this condition by placing a lower bound of 60 and an upper bound of 80 on the microcontroller. We also make the assumption that if the temperature in room one changes by X degrees, it will also change by X degrees in rooms two and three. In order to explain our approach, several variables need to be defined:

Crmax = Room with fastest cooling rate

Crmin = Room with slowest cooling rate

TprefX = Temperature preference in room X

This approach follows a simple averaging scheme. The idea is to achieve a desired temperature in rooms 1, 2, and 3. Because all of the rooms are governed by the same steam valve and there exists a heat gradient between rooms, accommodating the exact desired temperatures within each room will be very difficult and nearly impossible. In this approach, we attempt to equally satisfy the temperature preferences through an average. Throughout the process, we will govern each individual room's temperature to ensure it is within the upper and lower bound limits.

To begin, we will profile the rooms and determine the room with the fastest cooling rate, Crmax, and the room with the slowest cooling rate, Crmin. Once determined, we will average the temperature preferences, TprefX, from all of the rooms and obtain a value between 60 and 80 degrees. We will then use this average temperature to accommodate the room with the fastest cooling rate while profiling the temperature within the other rooms. Since this room cools faster than the others, the one with the slowest cooling rate, Crmin, will heat up faster. This characteristic can potentially cause the room, Crmin, to heat to an uncomfortable temperature. In the case that the temperature within Crmin exceeds the value of the average temperature by an X amount of degrees, we will change our control to accommodate the averaged temperature within Crmin. Eventually, someone will change their temperature preference and we will have to accommodate a new average or the room with the fastest cooling rate, Crmax, will fall below the value of the averaged temperature by an X amount of degrees, in which case we would switch our control to accommodate the averaged temperature within Crmax.

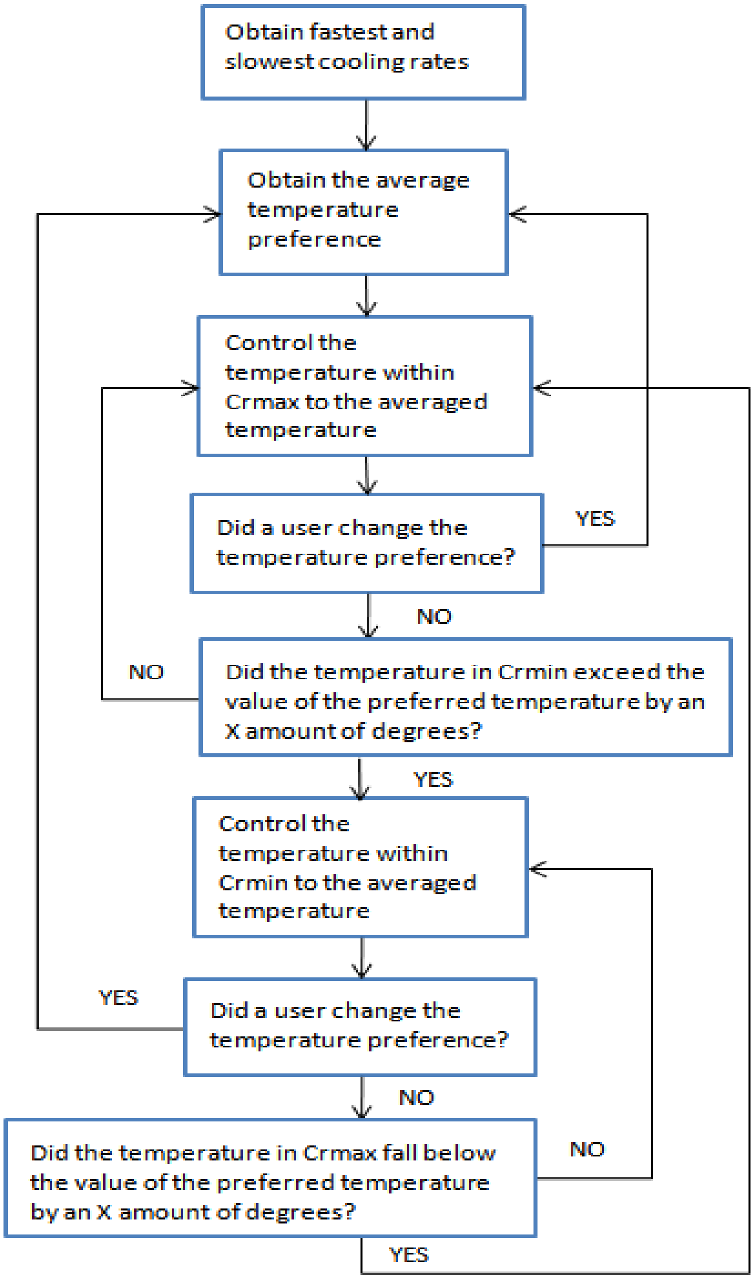

Obtain fastest and slowest cooling rates
Obtain the average temperature preference
Control the temperature within Crmax to the averaged temperature
Did a user change the temperature preference?
YES
NO
Did the temperature in Crmin exceed the value of the preferred temperature by an X amount of degrees?
NO
YES
Control the temperature within Crmin to the averaged 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

Figure 22: Set point algorithm logic diagram approach 1

Approach 2

In this second approach, we make the same assumption that the user will always enter a temperature between 60 and 80 degrees. We can ensure this condition by placing a lower bound of 60 and an upper bound of 80 on the microcontroller. We also make the assumption that if the temperature in room one changes by X degrees, it will also change by X degrees in rooms two and three. In order to explain our approach, several variables need to be defined:

Crmax = Room with fastest cooling rate

Crmin = Room with slowest cooling rate

TprefX = Temperature preference in room X

TcurX = Current temperature in room X

Δ12 = Tcur2-Tcur1

Δ23 = Tcur3-Tcur2

This approach follows a logic scheme in determining temperature set point and uses temperature frequency values to accommodate a certain temperature. The idea is still to achieve a desired temperature in rooms 1, 2, and 3. In this approach, we attempt to satisfy the preference temperature by following a logical pattern and accommodating different rooms at different times. Through this approach, some individuals will receive their desired temperatures a portion of the time and the remaining individuals will receive their desired temperatures the remaining amount of time. As before, we will govern each individual room's temperature to ensure it is within the upper and lower bound limits.

To begin, we will profile the rooms and determine the room with the fastest cooling rate, Crmax, and the room with the slowest cooling rate, Crmin. Afterward, we will determine the temperature differences between rooms one and two, Δ12, as well as rooms two and three, Δ23. Once we know the temperature differences between rooms, we also know a range of temperatures that we can accommodate in a certain room without violating the lower and upper limits of room temperature in the adjacent rooms. Using these ideas, we formulate the following equation assuming a three room system:

$$tsetmax = T\max + (Tpref1 - Tcur1)*G1 + (Tpref2 - Tcur2)*G2 + (Tpref3 - Tcur3)*G3$$
$$tsetmin = T\min + (Tpref1 - Tcur1)*G1 + (Tpref2 - Tcur2)*G2 + (Tpref3 - Tcur3)*G3$$

The above equation helps us determine a temperature set point, tsetmax or tsetmin, which the system needs to accommodate in either Crmax or Crmin depending on the state of the system. Tmax/Tmin is the temperature value in Crmin/Crmax at the time of setting or changing the value of tset. The G signals are Boolean value signals determined by a simple logic equation. Only one of the G signals can be high at one time – much like the output of a decoder.

The idea here is to obtain a user's desired temperature TprefX and determine the difference between TprefX and TcurX. This gives us the amount of temperature the system will change, in all adjacent rooms, if this temperature is accommodated. Now, we use the logic governing G1 to determine whether accommodating this temperature will violate the upper and lower temperature limits within any of the adjacent rooms by considering TprefX – TcurX as well as Δ12 and Δ23. If so, we set that value of GX to zero, meaning that we throw that preference out. If not, we move to the next portion of the logic algorithm, GX, and determine whether governing a desired temperature in one room will satisfy the desired temperature within adjacent rooms with +/- Y degrees of error calculated from the temperature gradients Δ12 and Δ23. Whichever room's preference satisfies the most rooms, the largest frequency temperature value determined by offsetting the desired temperature by Δ12 and Δ23, we decide to accommodate the temperature preference for that particular room. In terms of GX, we set that value to one and all others to zero. Now, to accommodate the appropriate temperature, we must offset TcurX within Crmax or Crmin at the time of tset by the difference of TprefX – TcurX, where X is the room with a preference that satisfies the largest number of rooms, and accommodate the tset temperature within Crmax or Crmin depending on the state of Crmax and Crmin.

The reason for referring to the states of Crmax and Crmin is because one room cools faster than the others and will always have the lowest temperature while the room with the slowest cooling rate, Crmin, will heat up faster. This characteristic can potentially cause the room, Crmin, to heat to an uncomfortable temperature. When we start our system, we will use the above equation for tsetmax, to accommodate Crmax for the appropriate change in temperature while profiling the temperature within the other rooms. In the case that the temperature within Crmin exceeds the value of the preferred temperature by an X amount of degrees, we will change our control to accommodate the preferred temperature within Crmin based on the value of tsetmin. Eventually, someone will change their temperature preference and we will have to accommodate a new tsetmax/testmin or the room with the fastest cooling rate, Crmax, will fall below the value of the preferred temperature by an X amount of degrees, in which case we would switch our control to accommodate the appropriate change in temperature within Crmax to tsetmax.

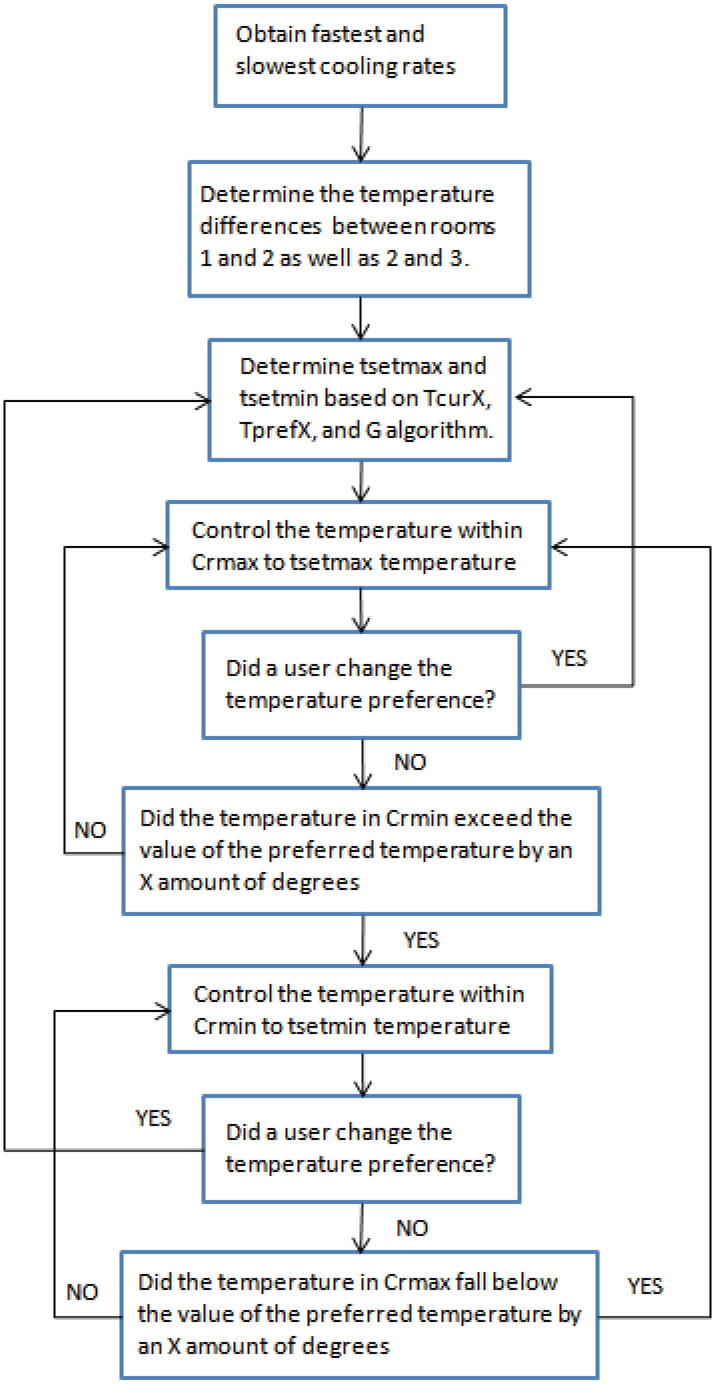

Obtain fastest and slowest cooling rates
Determine the temperature differences between rooms 1 and 2 as well as 2 and 3.
Determine tsetmax and tsetmin based on TcurX, TprefX, and G algorithm.
Control the temperature within Crmax to tsetmax temperature
Did a user change the temperature preference?
YES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

Figure 23: Set point algorithm logic diagram approach 2

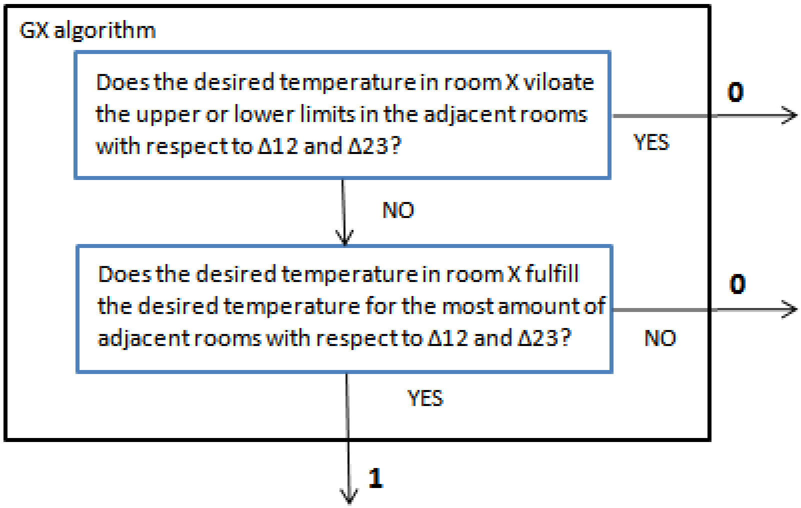

GX algorithm
Does the desired temperature in room X viloate the upper or lower limits in the adjacent rooms with respect to Δ12 and Δ23?
YES
0
NO
Does the desired temperature in room X fulfill the desired temperature for the most amount of adjacent rooms with respect to Δ12 and Δ23?
NO
0
YES
1

Figure 24: Set point GX algorithm logic diagram

Wireless transceiver: The wireless transceiver will be attached to the PCB using a socket for easy removal. This will allow the unit to be easily removed and programmed externally. The Xbee can then be programmed using a GUI provided by the manufacturer. The Xbee will need to have the PAN ID, channel number, unit address, and destination address set along with a number of other settings including the baud rate and turning on the API frame mode. The API frame mode was chosen over the transparent mode to ensure reliable operation.

Once the wireless transceiver has been programmed it will be inserted into its socket on the PCB. The physical connections of the transceiver are shown in the figures below.

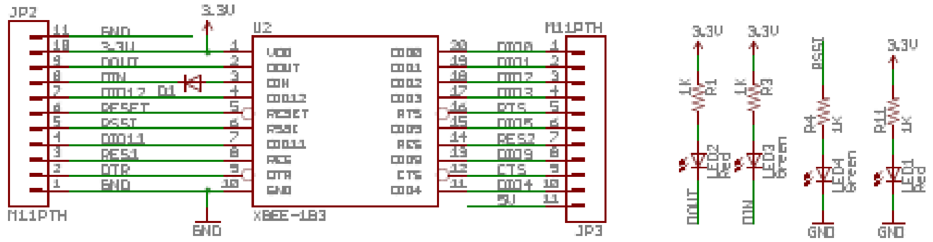
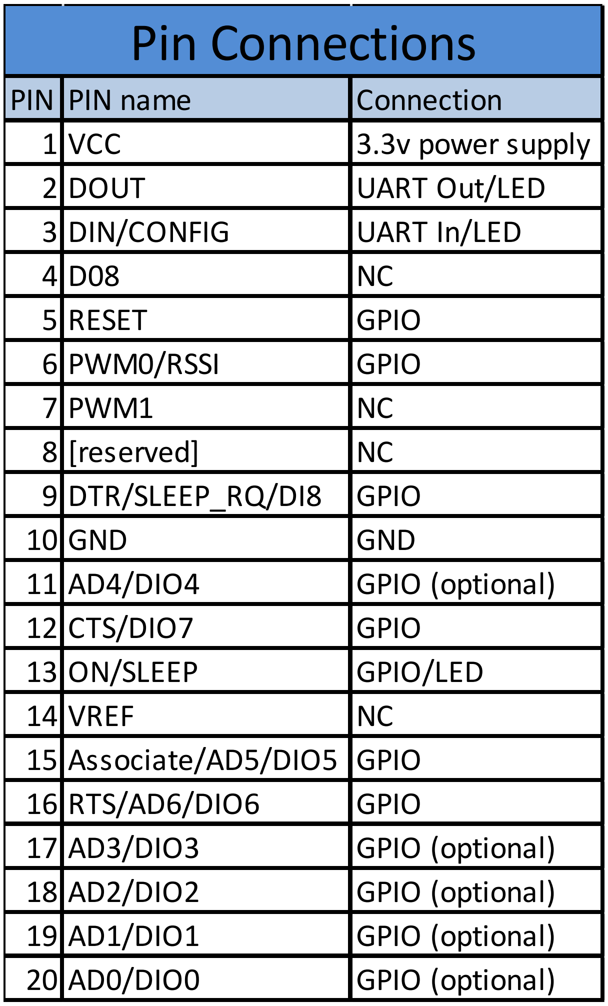


Figure 25: Schematic for the wireless transceiver



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)

Figure 26: Pin connections for the wireless transceiver

Controller Unit Power System Detailed Design

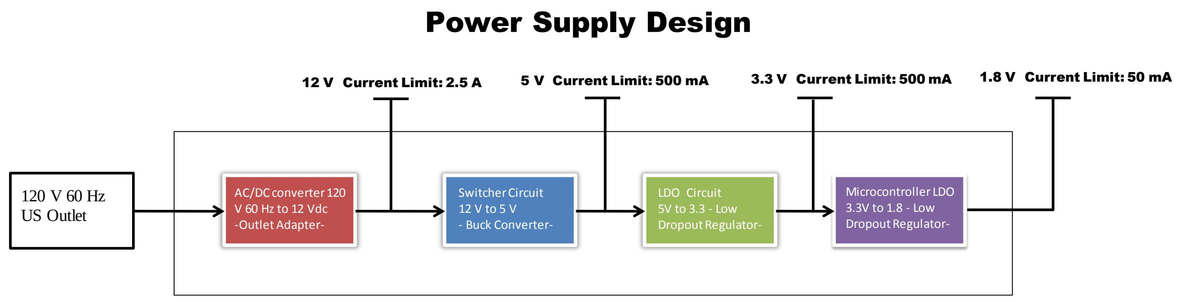

Power Supply Design
12 V Current Limit: 2.5 A
5 V Current Limit: 500 mA
3.3 V Current Limit: 500 mA
1.8 V Current Limit: 50 mA
120 V 60 Hz US Outlet
AC/DC converter 120 V 60 Hz to 12 Vdc -Outlet Adapter-
Switcher Circuit 12 V to 5 V - Buck Converter-
LDO Circuit 5V to 3.3 - Low Dropout Regulator-
Microcontroller LDO 3.3V to 1.8 - Low Dropout Regulator-

Figure 27: Controller unit power supply diagram

The above block diagram represents a high level design of the controller unit power system. The motor unit is a high power device that requires a lot of current draw. Therefore, we will power this unit using a standard US outlet, 120 V 60 Hz. Our group has not yet implemented the power system design in our schematic because we want to assure that we know the actual power ratings of the system. As we implement our schematic design, we find the need to add other IC chips. Therefore, we do not want to under design or over design the power system until all of the appropriate components are set in place. The following table represents the power ratings of the units that we are implementing:

Power Supply Spec		
Device	Supply Voltage	Max Current Draw
LCD	3.3 V	300 uA
LCD Backlight	3.3 V	40 mA
LED Driver Circuit	3.3 V	1.5 mA
Temp Sensor	3.3 V	60 uA
Microcontroller	3.3 and 1.8	36.3 mA
DC Motor	12 V	1.3 A
Ethernet Transceiver	3.3 V	81.6 mA
Voltage Detector	3.3 V	3.5 uA
NiMH Charger	3.3 V	300 uA
Xbee Transceiver	3.3 V	250 mA

Figure 28: Power supply specifications

Using this data, our group has a good understanding of the power requirements of our system. Because the system will be powered through a standard US outlet, we are considering an AC to DC converter such as the Phihong PSC30R-120-R, rated at 12 V and 2.5 A. Because this rail is provided by an outlet, we will implement reverse diode protection circuitry to safeguard our system from lightning and will implement voltage limitation circuitry to maintain the rail voltage within a desired range. We will also use a bypass scheme to filter and reduce noise on this line. Using this rail, we will power the motor driver circuitry as well as the motor itself. On this rail, we will use a switcher circuit, buck converter, in order to achieve a 5 Vdc from the 12 Vdc signal. Because the switcher will operate at a particular frequency and will have a noisy output, we will implement various bypass schemes to reduce the noise on this line. The 5 V signal will be used power the motor driver circuitry and can be used to power the LCD as well as some IC chips on the controller unit. Since group is attempting to implement one PCB for the entire controller unit as well as the user interface, which is powered by 2 AA NiMH batteries, it is in our best interests to keep the power system design as similar as possible. Therefore, we will try to power most of our system off of the next portion of power circuitry. The next portion of the power supply will consist of an LDO, low dropout regulator, chip that will provide a 3.3 Vdc signal from the 5 Vdc input. The LDO will not produce much noise and can be handled with a few bypass capacitors. This rail will be used to power a major portion of our system and will have to have a high power rating since we are attempting to use the same power design scheme for two PCBs. The final rail of our system consists of internal 1.8 Vdc regulators within the microcontroller as well as the LCD that will power to internal IC chipsets.

User Interface Power System Detailed Design

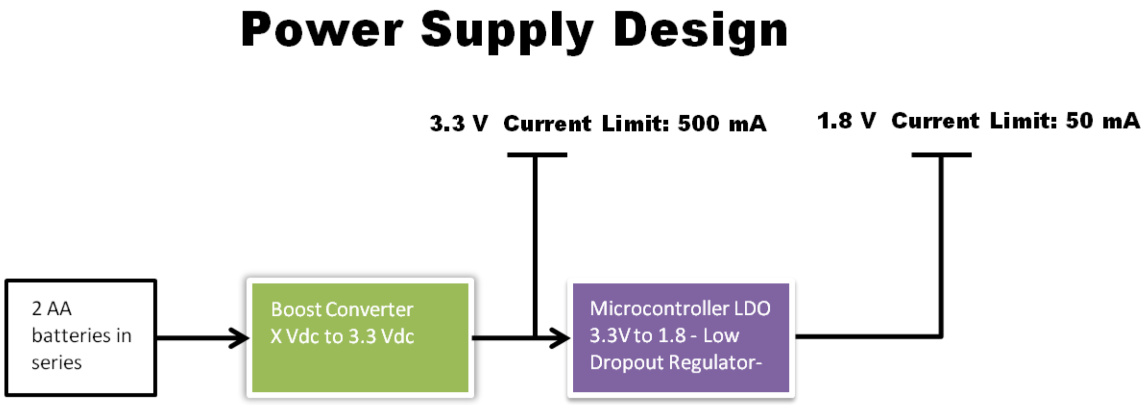

Power Supply Design
3.3 V Current Limit: 500 mA
1.8 V Current Limit: 50 mA
2 AA batteries in series
Boost Converter X Vdc to 3.3 Vdc
Microcontroller LDO 3.3V to 1.8 - Low Dropout Regulator-

Figure 29: User interface power supply diagram

The above block diagram represents a high level design of the user interface unit power system. As explained in the previous section, our group has not yet implemented the power system design in our schematic because we want to assure that we know the actual power ratings of the system. As we implement our schematic design, we find the need to add other IC chips. Therefore, we do not want to under design or over design the power system until all of the appropriate components are set in place. We again used figure 28 to represent the power ratings of the units that we are implementing.

The power system of the user interface unit is slightly simpler to implement because it only requires two rails. The input power from the system will consist of two AA NiMH batteries in series. There will again be some form of ESD protection circuitry on the input as well as a bypass scheme to smooth out the battery voltage rail. Because batteries do not keep a constant voltage over a given amount of time, our group has decided to implement a boost converter in order to provide a constant 3.3 Vdc signal for an input that fits within a specified voltage range. Typical NiMH batteries are 1.5 V and tend to slope down to 1.2 V throughout their lifetime. Therefore, the boost converter will be designed to provide a 3.3 Vdc signal from an input range between 2 V and 3.5 V. As before, we will implement some sort of bypassing scheme due to the noise on the boost converter output pin due to the switching noise. As in the previous case, we will utilize the internal 1.8 V LDOs from the microcontroller and LCD to power internal IC chipsets in an effort to save money on another LDO implementation.

Recharging System

In an attempt to cut down on long term costs, the group designed the user interface unit to use two rechargeable NiMH AA batteries. We have implemented two forms of circuitry in order to handle the recharging functionally of the unit. The first portion of the design consists of a bq2002C chipset that we have used in order to implement a NiMH charger. This is a very simple design that checks to see whether a 5 V USB supply is present. If it is present, the unit will begin charging the two AA batteries. If the unit takes an X amount of time to recharge the batteries, if it senses too much heat dissipation, or if the unit senses a sudden battery voltage drop off, it will stop charging the batteries and will signal that the batteries have charged. The design implementation is demonstrated below:

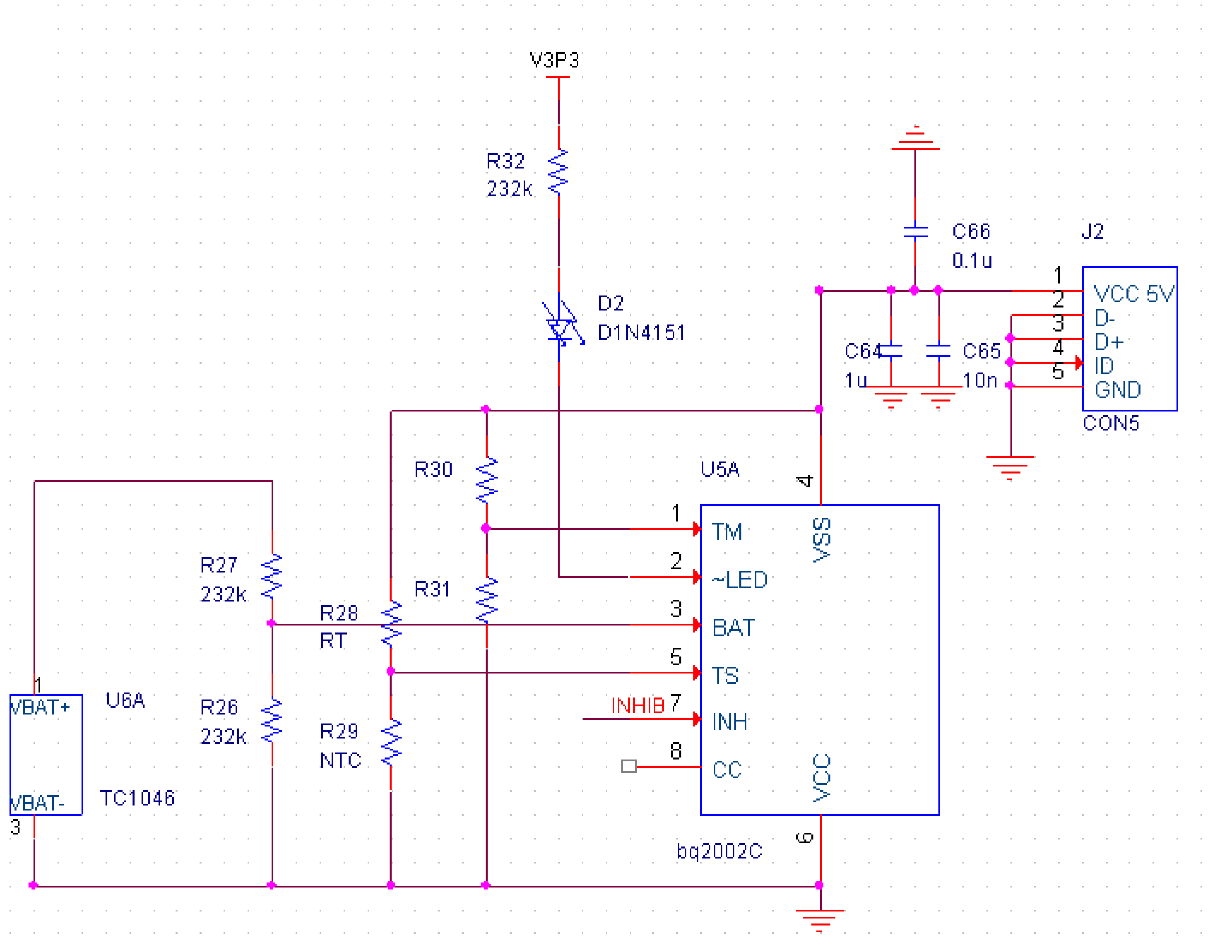


Figure 30: User interface battery charging circuitry schematic

The next portion of circuitry needed to implement this system simply indicates that the battery power unit is below a usable voltage and that the batteries need to be recharged. As of now, the system utilizes a Seiko Instruments voltage detector in order to sense the drop in battery voltage. The group will use this signal to warn the microprocessor to prompt the user to charge the unit. A beeper alarm might be implemented in order to warn the user.

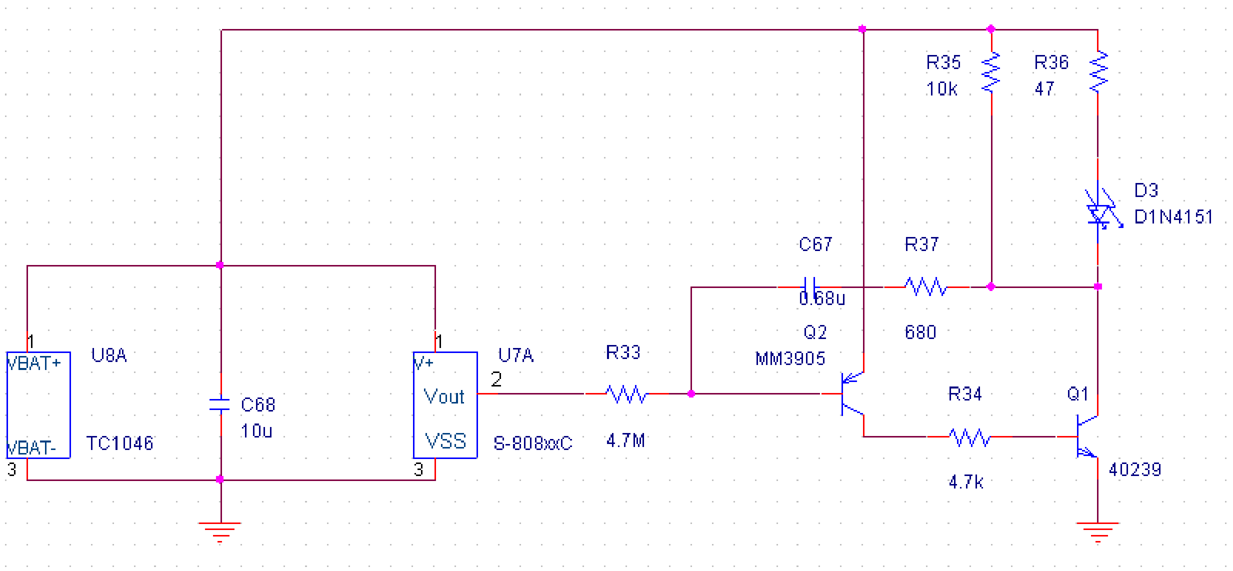


Figure 31: Low battery charge indicator

Using these two systems in sync with the microcontroller, we will implement the following functionality:

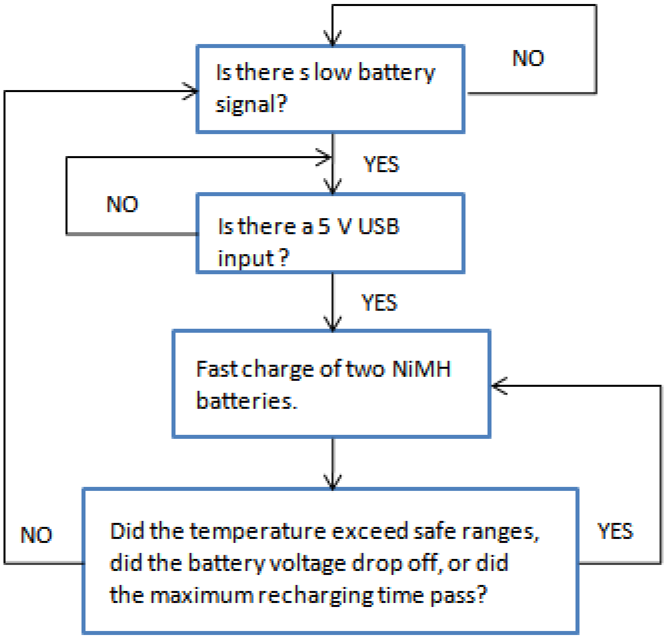
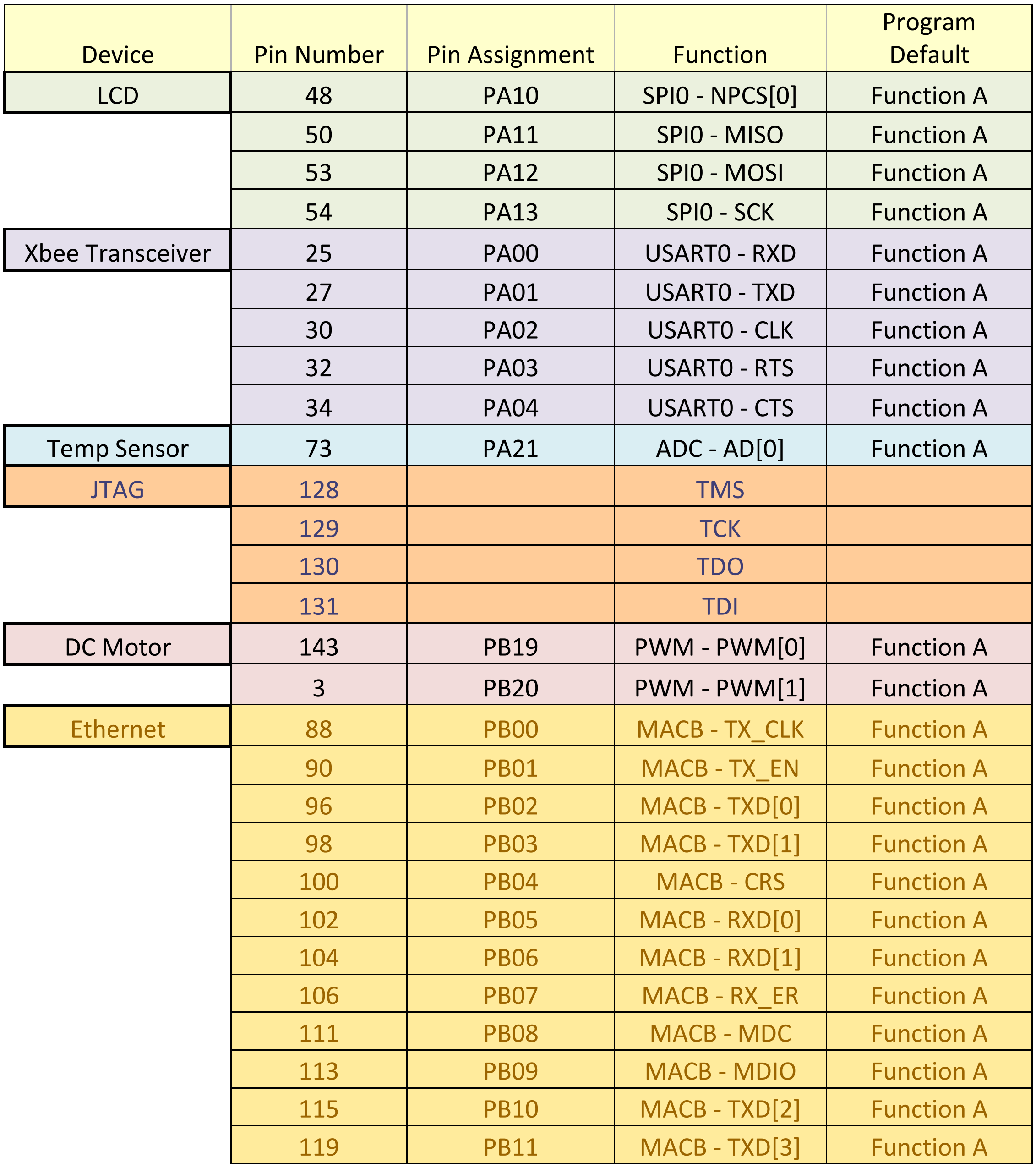

Is there s low battery signal?
NO
YES
NO
Is there a 5 V USB input ?
YES
Fast charge of two NiMH batteries.
Did the temperature exceed safe ranges, did the battery voltage drop off, or did the maximum recharging time pass?
NO
YES

Figure 32: Battery charge circuitry Conceptual Diagram

When the unit is finished charging, the microcontroller will receive a signal from the charger and inhibit the charger from supplying current to the batteries. As the voltage drops below usable levels, the voltage detector will trigger and signal to the microcontroller that the batteries are low. In this case, the unit will alarm the user to charge the batteries by plugging the unit into a PC via USB. Once the batteries are charged, the process will repeat.

Microcontroller

The first step in the microcontroller implementation was to mux the appropriate functionality to the proper pins. Once complete, we would use these pins to communicate to the system peripherals. Our microprocessor has 144 available pins. We are anticipating using 60 to 70 percent of these pins in this project. We are only 60 percent completed with our schematic design and are not certain what more will be implemented through the microcontroller. Our group is using SPI to control the LCD, USART to control the Xbee transceiver, ADC to receive data from the temperature sensor, the standard JTAG to program the microcontroller, PWM in order to run the DC motor, and an Ethernet MAC interface to communicate to an Ethernet transceiver and the Iowa State University network. The table below demonstrates what functionality will be mixed to what pin in the 60 percent of our implementation:



Device	Pin Number	Pin Assignment	Function	Program Default
LCD	48	PA10	SPI0 - NPCS[0]	Function A
	50	PA11	SPI0 - MISO	Function A
	53	PA12	SPI0 - MOSI	Function A
	54	PA13	SPI0 - SCK	Function A
Xbee Transceiver	25	PA00	USART0 - RXD	Function A
	27	PA01	USART0 - TXD	Function A
	30	PA02	USART0 - CLK	Function A
	32	PA03	USART0 - RTS	Function A
	34	PA04	USART0 - CTS	Function A
Temp Sensor	73	PA21	ADC - AD[0]	Function A
JTAG	128		TMS	
	129		TCK	
	130		TDO	
	131		TDI	
DC Motor	143	PB19	PWM - PWM[0]	Function A
	3	PB20	PWM - PWM[1]	Function A
Ethernet	88	PB00	MACB - TX_CLK	Function A
	90	PB01	MACB - TX_EN	Function A
	96	PB02	MACB - TXD[0]	Function A
	98	PB03	MACB - TXD[1]	Function A
	100	PB04	MACB - CRS	Function A
	102	PB05	MACB - RXD[0]	Function A
	104	PB06	MACB - RXD[1]	Function A
	106	PB07	MACB - RX_ER	Function A
	111	PB08	MACB - MDC	Function A
	113	PB09	MACB - MDIO	Function A
	115	PB10	MACB - TXD[2]	Function A
	119	PB11	MACB - TXD[3]	Function A

Figure 33: Microcontroller Pin Assignment table

The next step was to translate this information to a schematic design. We began by implementing all of the microcontroller power rails and appropriate bypass capacitors. We then labeled the appropriate pins and connected them to the appropriate peripherals, checking pin voltage and current ratings to determine whether any signal and level conversion would have to be implemented. As of now, all of the signal lines are direct connections using in series low ohm resistors or bypass capacitors. The microcontroller schematic implementation is shown below without any peripheral connections:

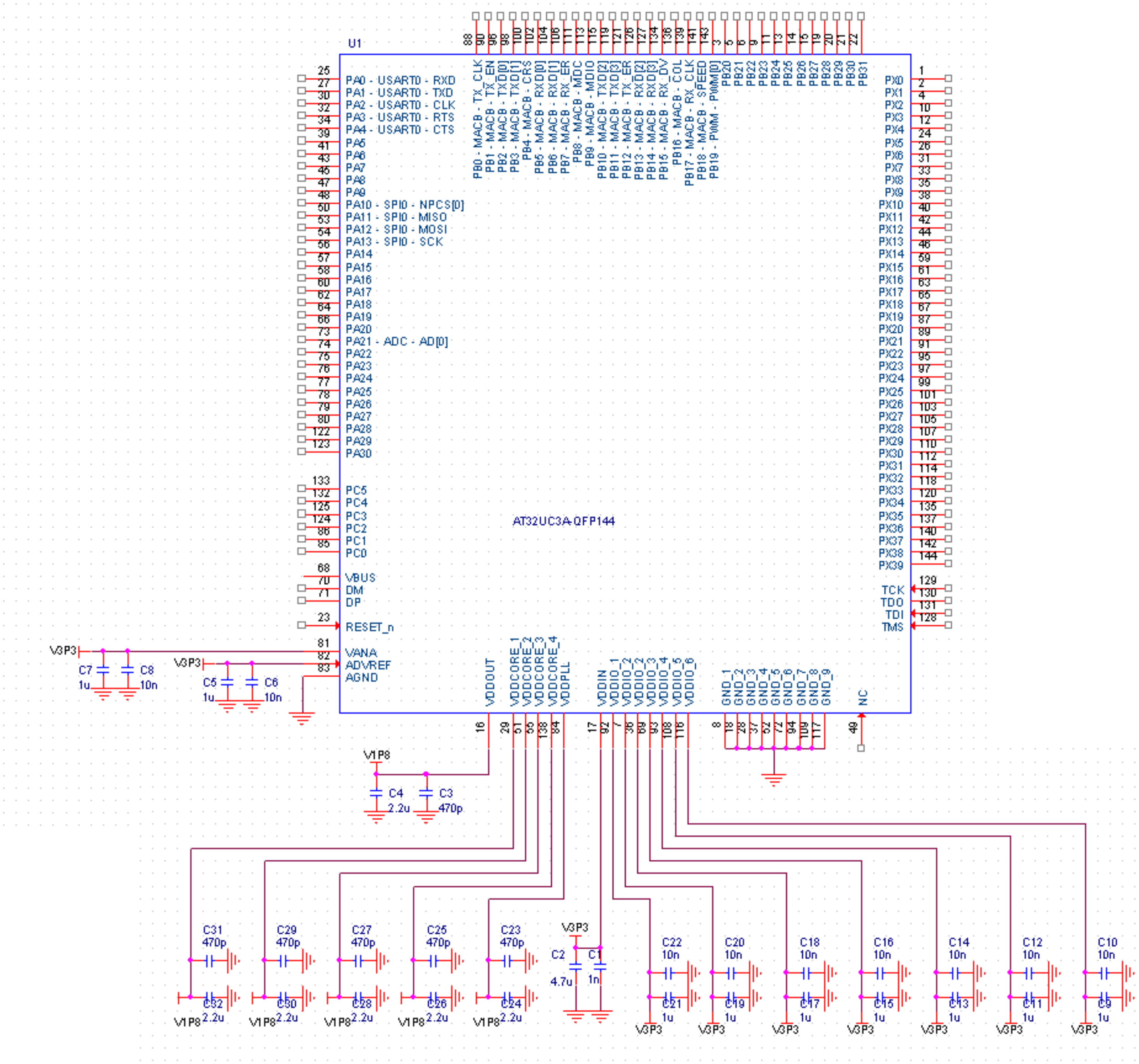


Figure 34: Microcontroller schematic

LCD Detailed Design

The LCD system design consists of two portions: the backlight design and the display design. The LCD has an internal driver that communicates commands from the microcontroller to the LCD through SPI protocol. The LCD can be run off of a single or multiple power supply. Because we are using 2 AA batteries, our group decided to implement the system using one power supply. Using the internal boost converters of the LCD, we placed capacitors in the appropriate locations in order to accommodate for a missing power supply and ensure high quality functionality. The power rail is bypassed with several capacitors in order to ensure a clean signal and high resolution for the intended viewer. The unit also requires several bypass capacitors to be placed on a majority of lines to filter any noise that may arise from the internal boost converters.

The backlight system is implemented through a high efficiency boost converter and constant current driver. The group decided to use this approach in order to extend the quality and life of the LED backlight. This portion of the system could have as easily been implemented through series resistors and transistors connected to a few GPIO lines. However, through our approach, we are able to ensure extended life of the LED backlight through exact current draw limitations, an enable signal that helps control system transient responses to LED shut down, and control the system to ensure exact power dissipation. The LCD backlight, LCD, and driver are shown below:

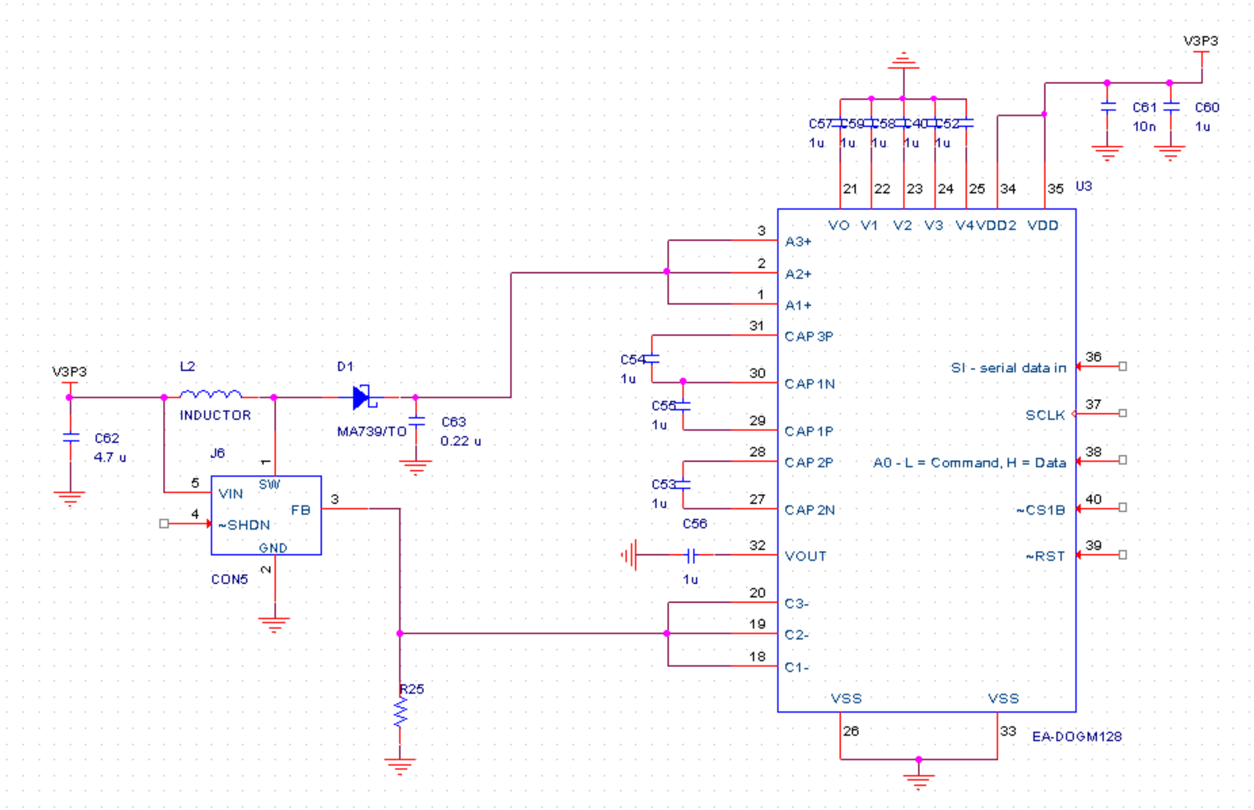


Figure 35: LCD schematic

Mechanical System

Stationary Platform

The following CAD design was done by our advisor, Lee Harker. We worked with Harker in selecting the appropriate materials and interconnect. The fabrication and machining of the finish product was performed by Harker.

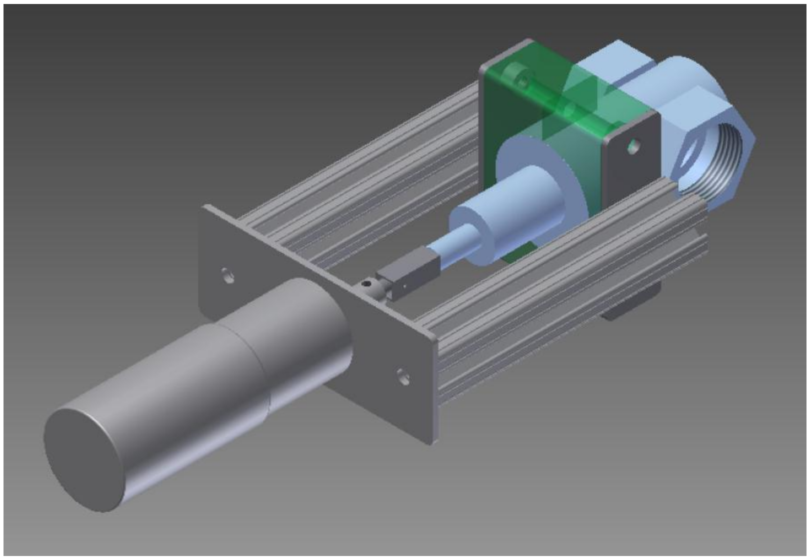


Figure 36: Stationary platform CAD design

From the CAD design, we have clamps that hold the stationary platform to the base of the steam valve. Then two extruded aluminum towers on the side to hold the gear motor mount. The gear motor will have four screws on the mount to hold the gear motor in place. Custom metal connection between the gear motor shaft and steam valve is designed by Harker. The connection will be designed to be easily detached.

With this design, we will achieve our main criteria of easy attachment/detachment and limit modification to the steam valve. With the appropriate stationary platform, we now move on to the design of the gear motor.

Gear motor

We identified the IG42 gear motor available from superdroidrobots.com to meet the minimum criteria for gear motor selection.

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

Figure 37: Gear motor specification

The IG42 gear motor operates can operate at 24V. This high operating voltage will increase the cost of implementing the power supply. However, when we looked at the speed and torque requirement of design, we determined that the gear motor would be able to deliver sufficient speed and torque when supplied with 12V. The results are that we implementation of power circuitry will have lower cost and power draw consumption will be reduced.

The accompanying magnetic shaft encoder came with the features listed below.

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

Figure 38: Shaft encoder specification

Although the magnetic shaft encoder only count 4 pulse per revolution, after applying the gear motor reduction ratio, the encoder is able to achieve 336 counts per revolution of the gear motor shaft. This comes how to be

$$\left(360\frac{degrees}{rev}\right)*\left(\frac{1}{336}\frac{rev}{pulse}\right) = 1.071\frac{degrees}{pulse}$$

There is roughly a one-to-one correlation between degrees and pulses. To resolve the fractional degrees lost per pulse, we will add back the missing 24 pulses per each complete revolution. This will also be prorated according to the degrees rotated.

$$degree\ rotation = degree\ rotation\ desired * \left(1+\frac{24}{360}\right)$$

This approach will help in improving the accuracy, but daily calibration will be needed to ensure consistent operation.

Bill of Materials

The following BOM detail is for implementing the mechanical system.

Item	Qty	Part
1	1	IG42 gear motor
2	1	L298N motor driver
3	4	diode
4	2	100uF capacitor
5	2	1Kohm resistor
6	1	2 ohm sense resistor

Figure 39: Gear motor specification

These parts can reference under schematic under Appendix A.

Functional Diagram

The following functional diagram shows the input and output relationship between modules interacting with the mechanical system.

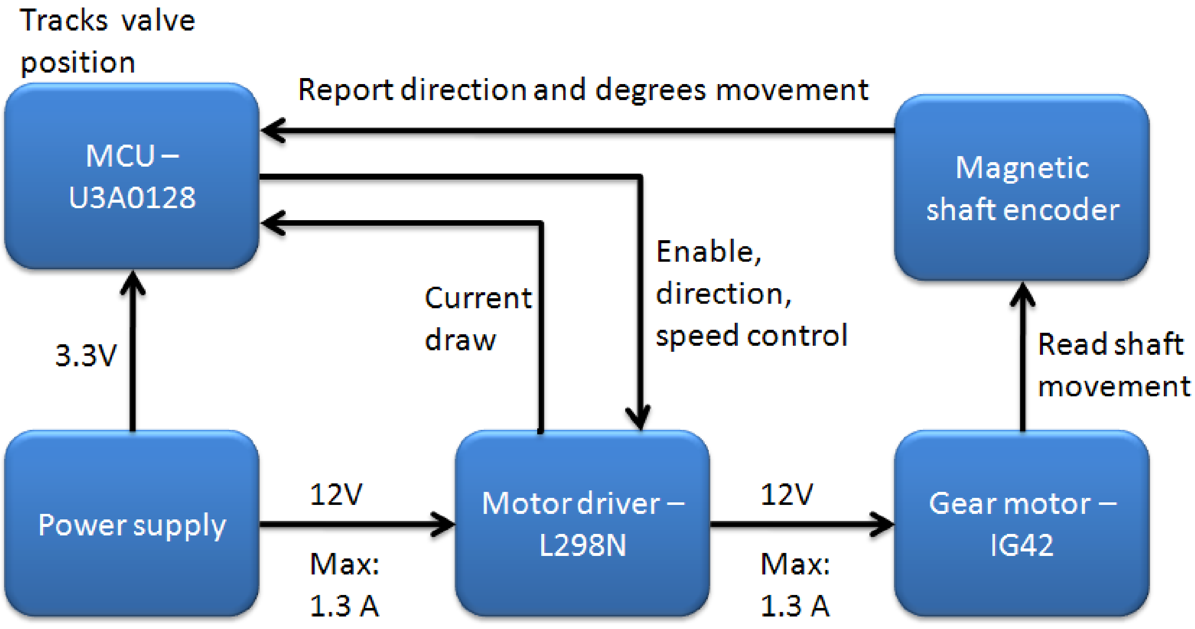


Figure 40: Mechanical Interface Interaction Diagram

Beginning with the power supply, it will supply 12V and a max current of 1.3A to the motor driver. The MCU generates the enable, direction, and speed through TTL and PWM signals to control the motor driver circuit. With the inputs, the motor driver is able to provide 12V and max of 1.3A to the gear motor and also provide current consumption feedback to the MCU. The rotation of the gear motor will be read by the integrated magnetic shaft encoder and that information is fed back to the MCU for processing.

With this functional system in place, the MCU will be able to control and track the rotation and position of the steam valve.

Logical Diagram

We have two logical implementation of the gear system software. Since the gear motor does not instantaneously stop when we command it to stop, the extra coasting of the gear motor will decrease our accuracy control.

To address this problem, we measured the extra coasting in degrees that the gear motor would have when fed with an instantaneous pulse. We then set the threshold value to be three times the extra coasting angular degrees. This will determine which set of speed the gear motor would use. The following two diagram shows two different method of rotating the steam valve.

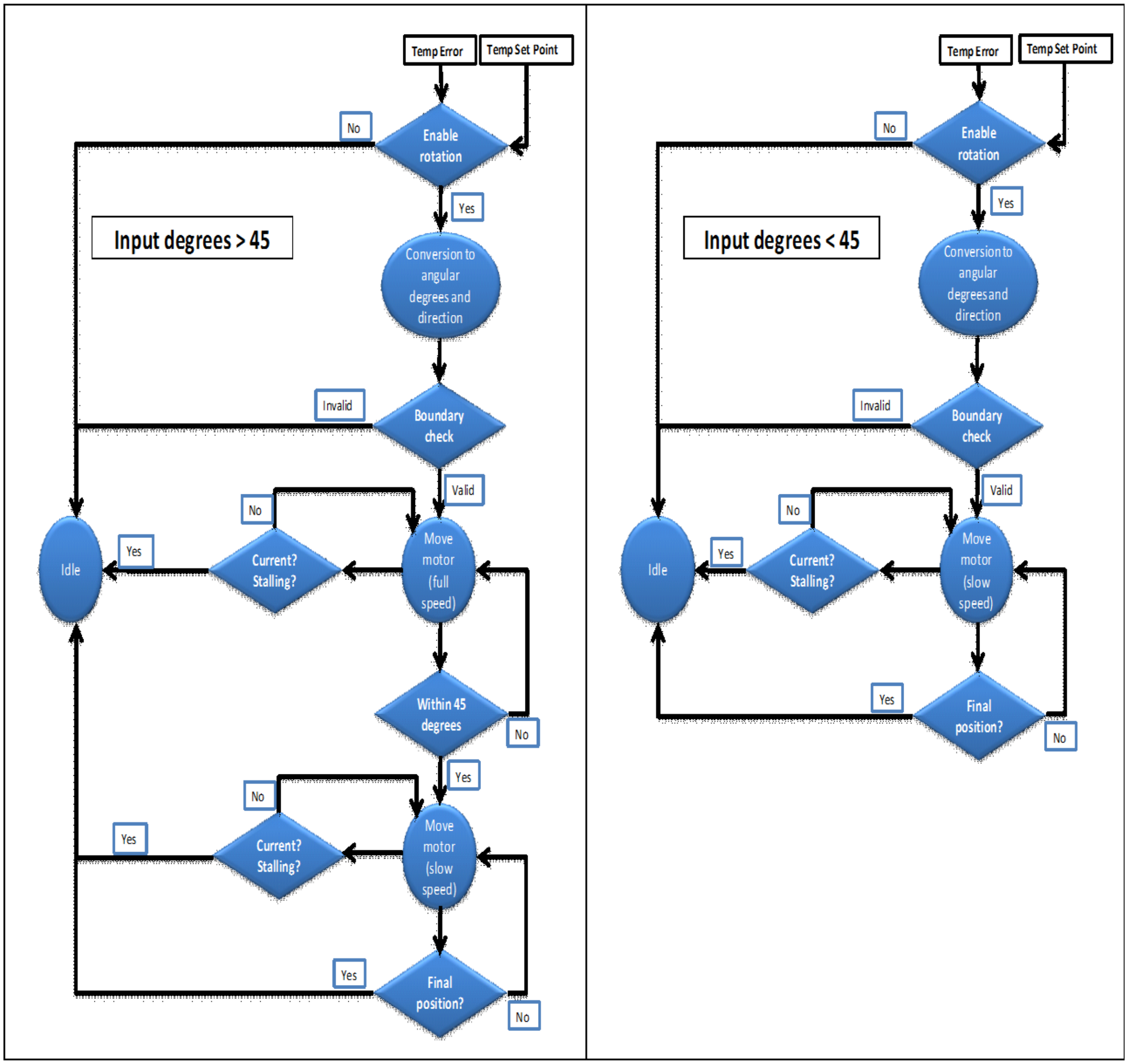


Figure 41: Gear motor logical diagram

Looking at the logical flow for input degrees greater than 45 degrees; we begin by receiving the inputs temperature error value and temperature set point from the controls system. We will enable rotation request only if a new temperature set point has been provided.

The next step after enabling the rotation process, we will convert the temperature error to a corresponding rotation that would reduce the temperature error to zero.   In order to perform this conversion, we will create the follow table where we could correlate temperature error to angular degrees rotation.

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

Figure 42: Temperature Error to Degrees Rotation Chart

For clarification, we assume the lower and upper limit of allowed temperature to be 60 and 80 degrees Fahrenheit respectively. This will limit our temperature error to be from -20 to 20 degrees Fahrenheit. The max limit for allowed rotation is 1800 angular degrees. This comes from the fact that the steam valve needs 5 full revolutions from fully close to fully open.

Since this table will only be applicable to one temperature, we will have to create 20 tables to accommodate the temperature range from 60 - 80 degrees Fahrenheit. We will generate these tables once automation of the mechanical and MCU is complete.

Now that we have the angular degrees to be rotated, we proceed to validate that the rotation will not exceed the fully close and fully open position. If the new position will exceed the boundary, the gear motor will idle and inform the MCU that the rotation cannot be perform. If the new position is valid, the gear motor will rotate at full speed towards the new position.

As the gear motor rotates, over current and stalling check will ensure the gear motor is actually moving. Should those checks go off, the gear motor will stop and the MCU will be informed of the situation. The next check is to slow down the gear motor once it is within 45 angular degrees of the final position. Again, the gear motor is subject to over current and stalling check as it rotates. The last check will confirm that the gear motor has rotated the steam valve to the desired position.

The other logical diagram is used when the rotation is less than 45 angular degrees. The only difference will be the gear motor will operate at slow speed from the beginning. This ensures that small angular turns will not have coasting problems at high speed.

This completes our detail design of the mechanical system. The gear motor description, BOM, functional diagram, and logical diagram will ensure the mechanical system operate as required for the project.

Temperature Sensor

Using the selection qualifications and design constraints, we were able to narrow down to the following selections:

Digi-Key Part Number	TC1046VNBTRCT-ND
Quantity Available	18,497
Manufacturer	Microchip Technology
Manufacturer Part Number	TC1046VNBTR
Description	IC TEMP-VOLT CONV PREC SOT23B
Lead Free Status / RoHS Status	Lead free / RoHS Compliant

Price Break	Unit Price	Extended Price
1	0.70	0.70
10	0.59	5.90
25	0.49	12.25
100	0.45	45.00

All prices are in US dollars.

Digi-Key Part Number	MCP9700A-E/TO-ND
Quantity Available	10,407
Manufacturer	Microchip Technology
Manufacturer Part Number	MCP9700A-E/TO
Description	IC SENSOR THERMAL 2.30 TO-92-3
Lead Free Status / RoHS Status	Lead free / RoHS Compliant

Price Break	Unit Price	Extended Price
1	0.34	0.34
10	0.31	3.10
25	0.26	6.50
100	0.24	24.00

Digi-Key Part Number	TMP36GRTZ-REEL7CT-ND
Quantity Available	18,956 Note
Manufacturer	Analog Devices Inc.
Manufacturer Part Number	TMP36GRTZ-REEL7
Description	IC SENSOR TEMP 2.7/5.5V SOT23-5
Lead Free Status / RoHS Status	Lead free / RoHS Compliant

Price Break	Unit Price	Extended Price
1	1.35	1.35
25	1.13	28.13
100	0.90	90.00
250	0.68	168.75
500	0.63	315.00
1,000	0.60	598.50

Figure 43: Temperature sensor selection table

In the end, we picked the High Precision Temperature-to-Voltage Converter TC1046VNBTRCT-ND. This is the ideal temperature sensor for our project. It has an ideal supply voltage range of 2.7 V to 4.4 V, wide temperature measurement Range: -40 degrees Fahrenheit to + 257 degrees Fahrenheit. It has a cheap unit price of $0.59 at the quantity of 10, and has almost 20,000 units available for order. Though the price when compared to the MCP9700A-E/TO-ND is slightly more, the TC1046VNBTRCT-ND's overall reliability, availability, and user rating is higher than MCP9700A-E/TO-ND. TC1046VNBTRCT-ND's unit price is about half of the price of TMP36GRTZ-REEL7CT-ND and when the two temperature sensor's features, reliability, and user ratings are compared showed very similar ratings. Though the TMP36GRTZ-REEL7CT-ND has a wider operation range from -40 degrees Fahrenheit to + 302 degrees Fahrenheit, both temperature sensors satisfy the required operation range for the project of 14 degrees Fahrenheit to 100 degrees Fahrenheit.

The team will be using pin 17 (ADC) from the microcontroller

Pin Number	Pin Assignment	Function	Program Default
73	PA21	ADC - AD[0]	Function A

Figure 44: Temperature sensor pin assignment

Below is the (Left) Schematic design for the temperature sensor. The Vout of the temperature sensor will be mapped to the microcontroller's pin 73 as shown in the functional block diagram below (right).

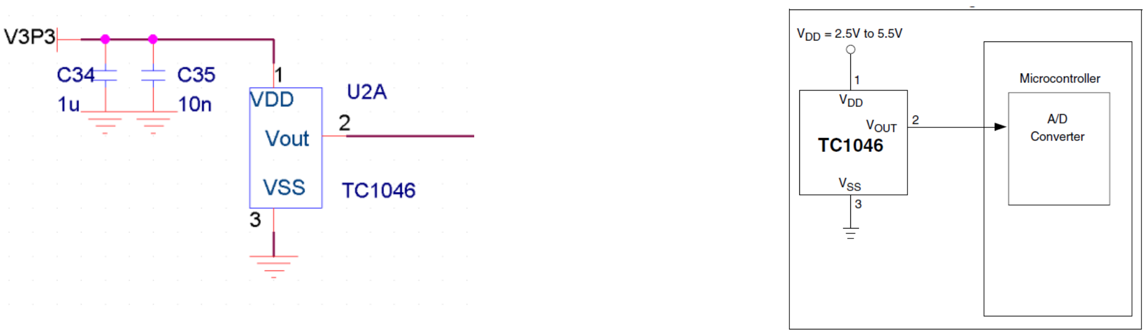
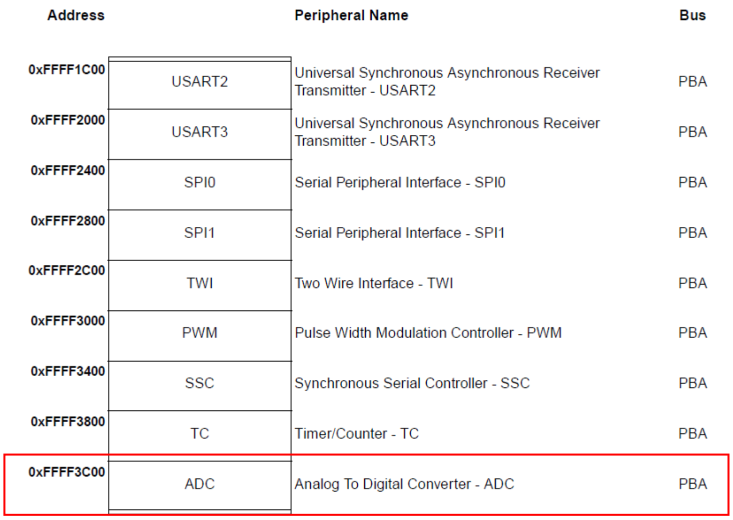


Figure 45: Temperature sensor schematic and functional diagram



Address		Peripheral Name	Bus
0xFFFF1C00	USART2	Universal Synchronous Asynchronous Receiver Transmitter - USART2	PBA
0xFFFF2000	USART3	Universal Synchronous Asynchronous Receiver Transmitter - USART3	PBA
0xFFFF2400	SPI0	Serial Peripheral Interface - SPI0	PBA
0xFFFF2800	SPI1	Serial Peripheral Interface - SPI1	PBA
0xFFFF2C00	TWI	Two Wire Interface - TWI	PBA
0xFFFF3000	PWM	Pulse Width Modulation Controller - PWM	PBA
0xFFFF3400	SSC	Synchronous Serial Controller - SSC	PBA
0xFFFF3800	TC	Timer/Counter - TC	PBA
0xFFFF3C00	ADC	Analog To Digital Converter - ADC	PBA

The Peripheral Address shown to the left shows the address value of 0xFFFF3C00 for the ADC. This will be used for the temperature sensor.

The ADC will be using is based on a Successive Approximation Register (SAR) 10-bit Analog-to-Digital Converter (ADC). We will be using the ADC_NB_CHANNELS-to-1 analog multiplexer to convert the analog signals from the temperature sensors to digital signals from the ADC_NB_CHANNELS analog lines as shown to the right.

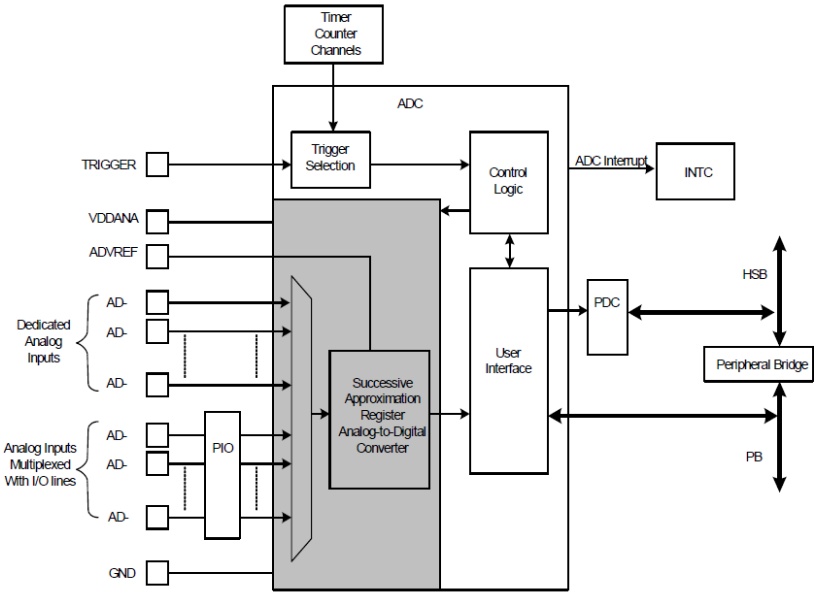
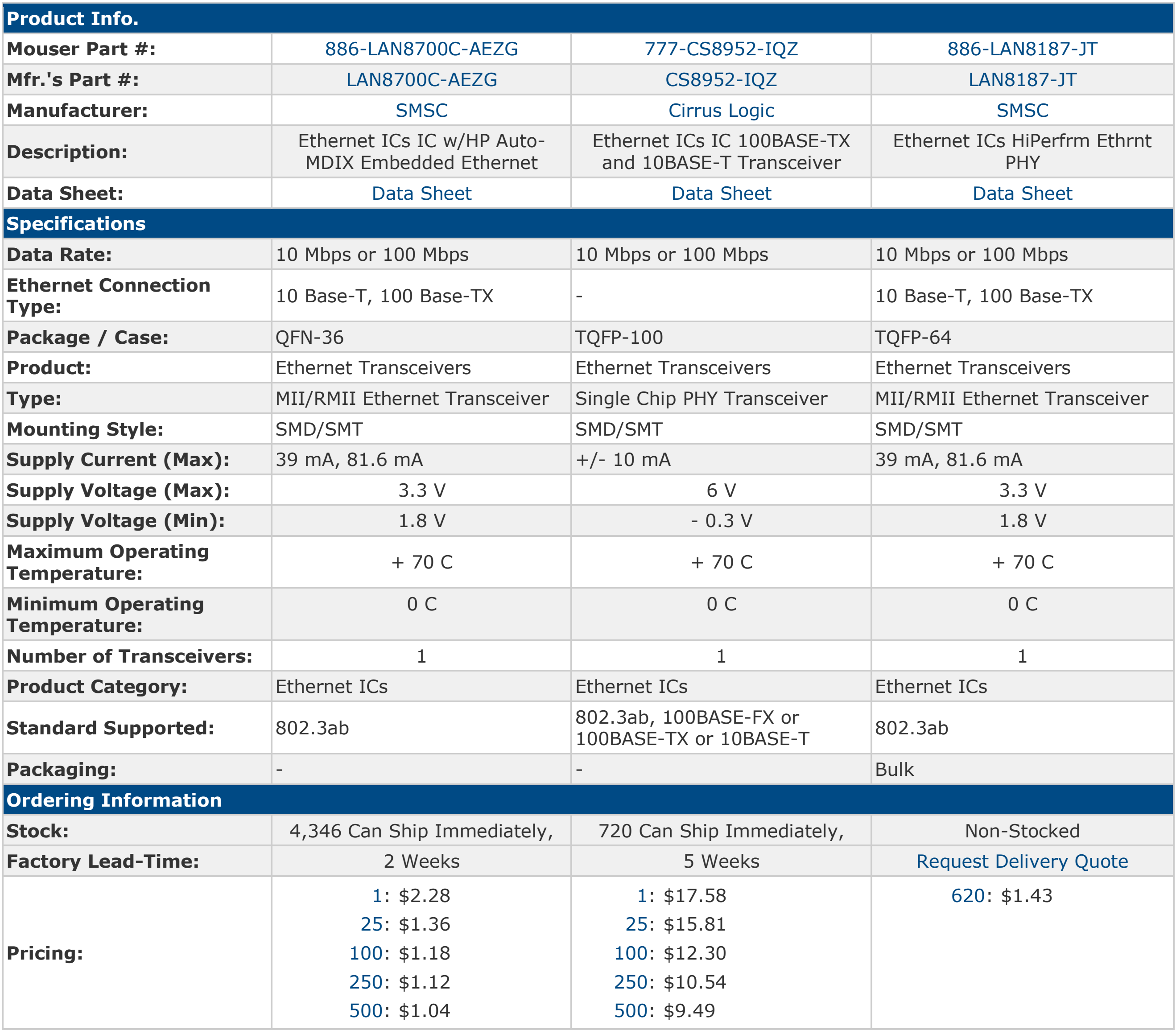


Figure 46: Microcontroller ADC for the temperature sensor

Ethernet Transceiver

Using the selection qualifications and design constraints, we were able to narrow down to the following selections:

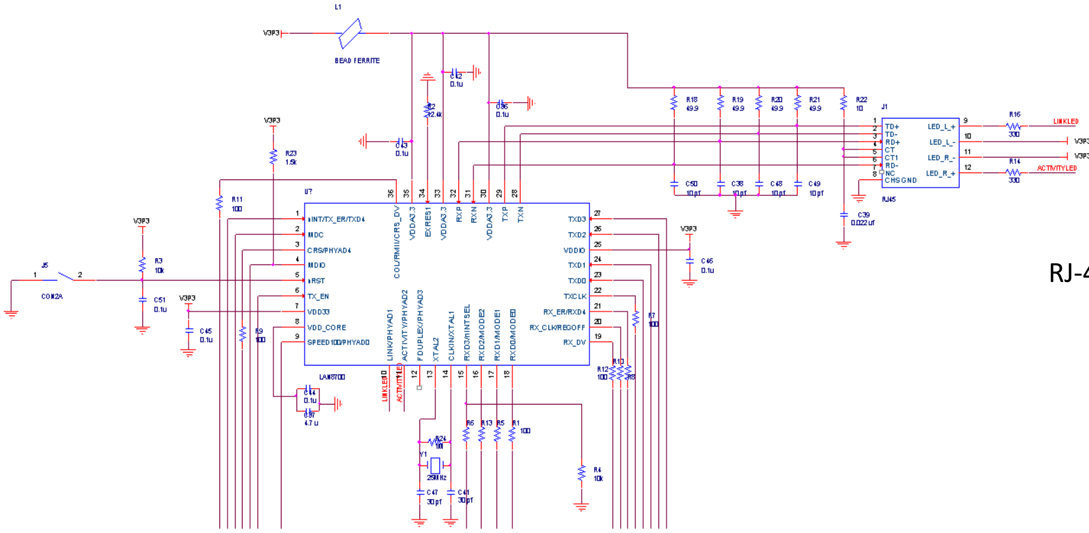


Product Info.			
Mouser Part #:	886-LAN8700C-AEZG	777-CS8952-IQZ	886-LAN8187-JT
Mfr.'s Part #:	LAN8700C-AEZG	CS8952-IQZ	LAN8187-JT
Manufacturer:	SMSC	Cirrus Logic	SMSC
Description:	Ethernet ICs IC w/HP Auto-MDIX Embedded Ethernet	Ethernet ICs IC 100BASE-TX and 10BASE-T Transceiver	Ethernet ICs HiPerfrm Ethrnt PHY
Data Sheet:	Data Sheet	Data Sheet	Data Sheet
Specifications			
Data Rate:	10 Mbps or 100 Mbps	10 Mbps or 100 Mbps	10 Mbps or 100 Mbps
Ethernet Connection Type:	10 Base-T, 100 Base-TX	-	10 Base-T, 100 Base-TX
Package / Case:	QFN-36	TQFP-100	TQFP-64
Product:	Ethernet Transceivers	Ethernet Transceivers	Ethernet Transceivers
Type:	MII/RMII Ethernet Transceiver	Single Chip PHY Transceiver	MII/RMII Ethernet Transceiver
Mounting Style:	SMD/SMT	SMD/SMT	SMD/SMT
Supply Current (Max):	39 mA, 81.6 mA	+/- 10 mA	39 mA, 81.6 mA
Supply Voltage (Max):	3.3 V	6 V	3.3 V
Supply Voltage (Min):	1.8 V	- 0.3 V	1.8 V
Maximum Operating Temperature:	+ 70 C	+ 70 C	+ 70 C
Minimum Operating Temperature:	0 C	0 C	0 C
Number of Transceivers:	1	1	1
Product Category:	Ethernet ICs	Ethernet ICs	Ethernet ICs
Standard Supported:	802.3ab	802.3ab, 100BASE-FX or 100BASE-TX or 10BASE-T	802.3ab
Packaging:	-	-	Bulk
Ordering Information			
Stock:	4,346 Can Ship Immediately,	720 Can Ship Immediately,	Non-Stocked
Factory Lead-Time:	2 Weeks	5 Weeks	Request Delivery Quote
Pricing:	1: $2.28 25: $1.36 100: $1.18 250: $1.12 500: $1.04	1: $17.58 25: $15.81 100: $12.30 250: $10.54 500: $9.49	620: $1.43

Figure 47: Ethernet transceiver options table

886-LAN8700C-AEZG was picked because of its high availability and cost. All three Ethernet transceivers have met the technical approach qualifications but only 886-LAN8700C-AEZG and 777-CS8952-IQZ are currently available and can be purchased individually. 886-LAN8700C-AEZG has over 4,000 in stock compared to the 700 in stock for 777-CS8952-IQZ and the price for 886-LAN8700C-AEZG is only $2.28 compared to 777-CS8952-IQZ's $17.58.

The details design of the Ethernet transceiver below shows all of its registers and components mappings. The Ethernet transceiver will only be placed in the microcontroller attached to the room with the steam valve. It will take the data of other rooms and transmit all of them to the Iowa State University network.



RJ-45 port

Figure 48: Ethernet transceiver schematic

The Ethernet transceiver will be using the microcontroller's pins as shown below.

Pin Number	Pin Assignment	Function	Program Default
88	PB00	MACB - TX_CLK	Function A
90	PB01	MACB - TX_EN	Function A
96	PB02	MACB - TXD[0]	Function A
98	PB03	MACB - TXD[1]	Function A
100	PB04	MACB - CRS	Function A
102	PB05	MACB - RXD[0]	Function A
104	PB06	MACB - RXD[1]	Function A
106	PB07	MACB - RX_ER	Function A
111	PB08	MACB - MDC	Function A
113	PB09	MACB - MDIO	Function A
115	PB10	MACB - TXD[2]	Function A
119	PB11	MACB - TXD[3]	Function A
121	PB12	MACB - TX_ER	Function A
126	PB13	MACB - RXD[2]	Function A
127	PB14	MACB - RXD[3]	Function A
134	PB15	MACB - RX_DV	Function A
136	PB16	MACB - COL	Function A
139	PB17	MACB - RX_CLK	Function A
141	PB18	MACB - SPEED	Function A

Figure 49: Ethernet transceiver pin connections

The diagram below shows the LAN8700 System Block Diagram where the MII interface will be mapped to the Ethernet controller from the microcontroller. We have deceived to use MII over RMII because MII contains more functionalities thus have more possibilities for future expendabilities.

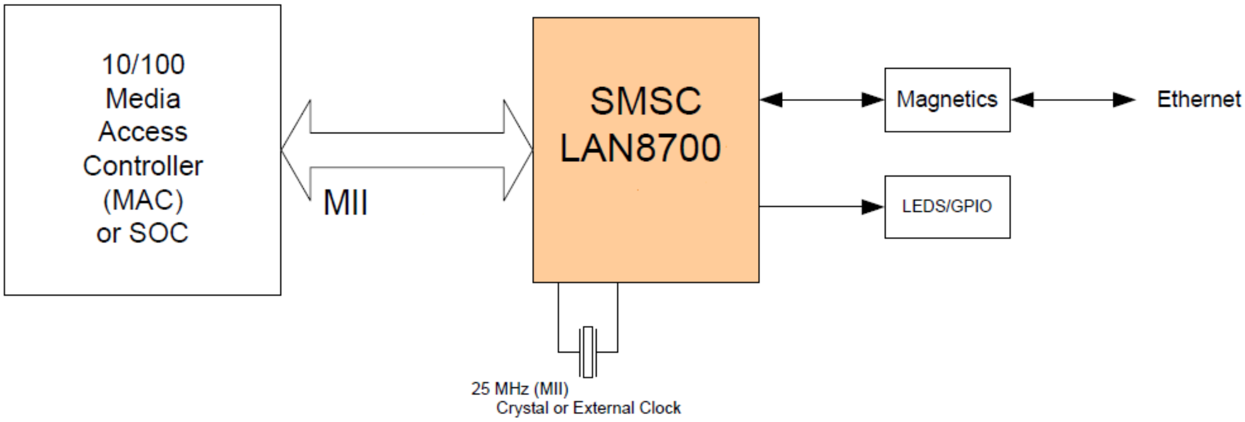
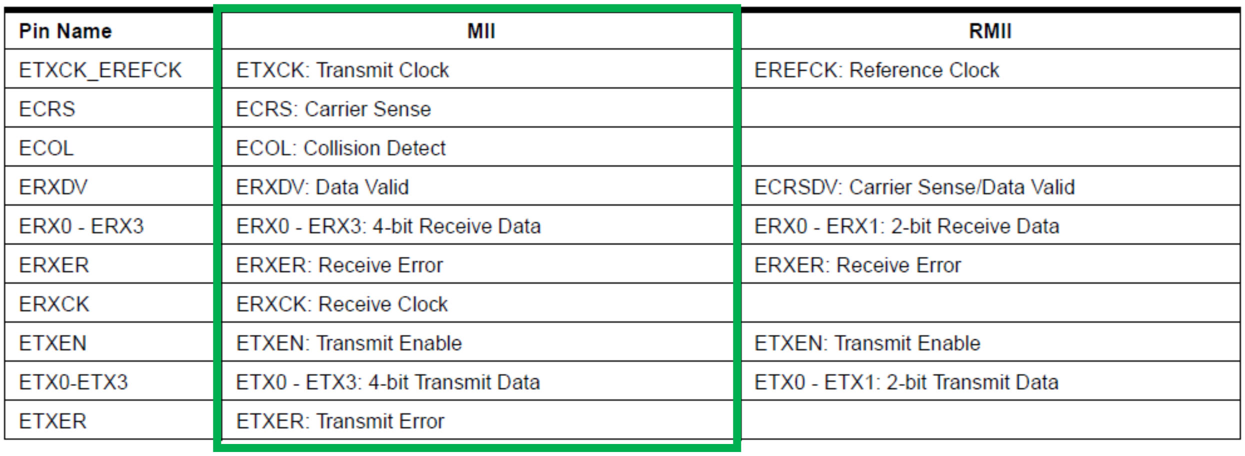


Figure 50: LAN8700 System Block Diagram

The team will use the pins shown below to implement the MII interface.



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	

Figure 51: MII Ethernet standard pin mapping table

The DMA controller will be using the Ethernet transceiver to perform six types of operation on the bus. In order of priority, these are:

1. Receive buffer manager write
2. Receive buffer manager read
3. Transmit data DMA read
4. Receive data DMA write
5. Transmit buffer manager read
6. Transmit buffer manager write

Website Interface

The block diagram below shows the relationship between the website interface and the steam heat valve controller system of three rooms. Note that only the room with the steam heat valve is able to communicate with the Ethernet interface. The Ethernet interface then talks with the website interface.

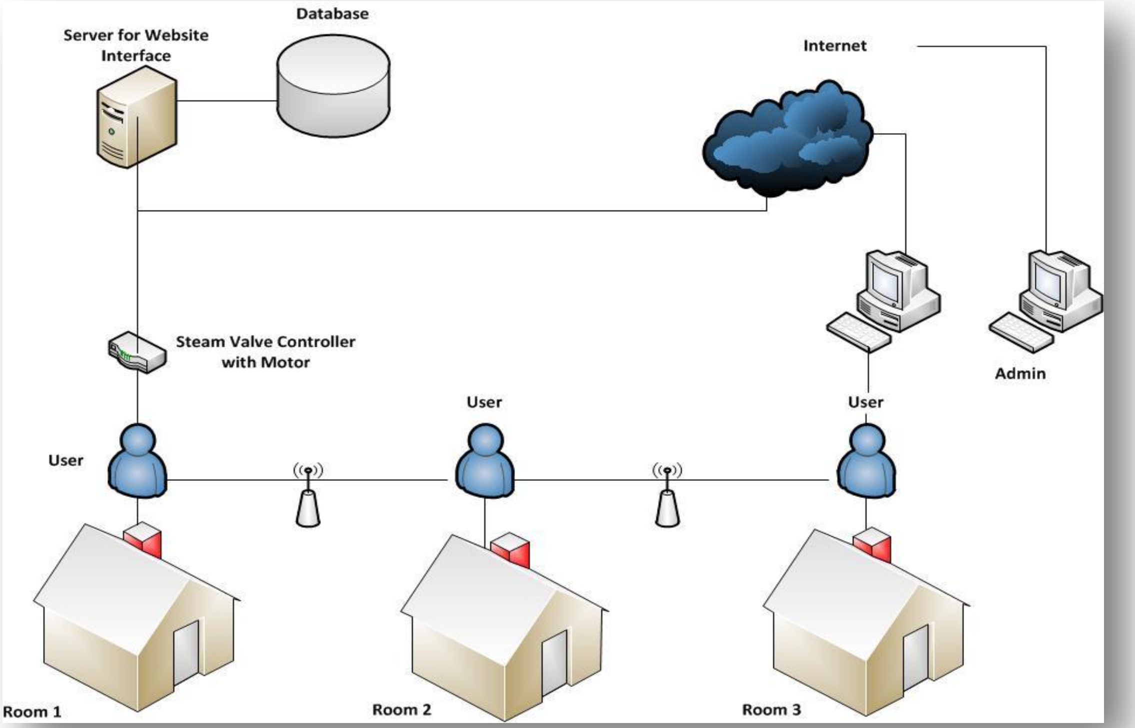
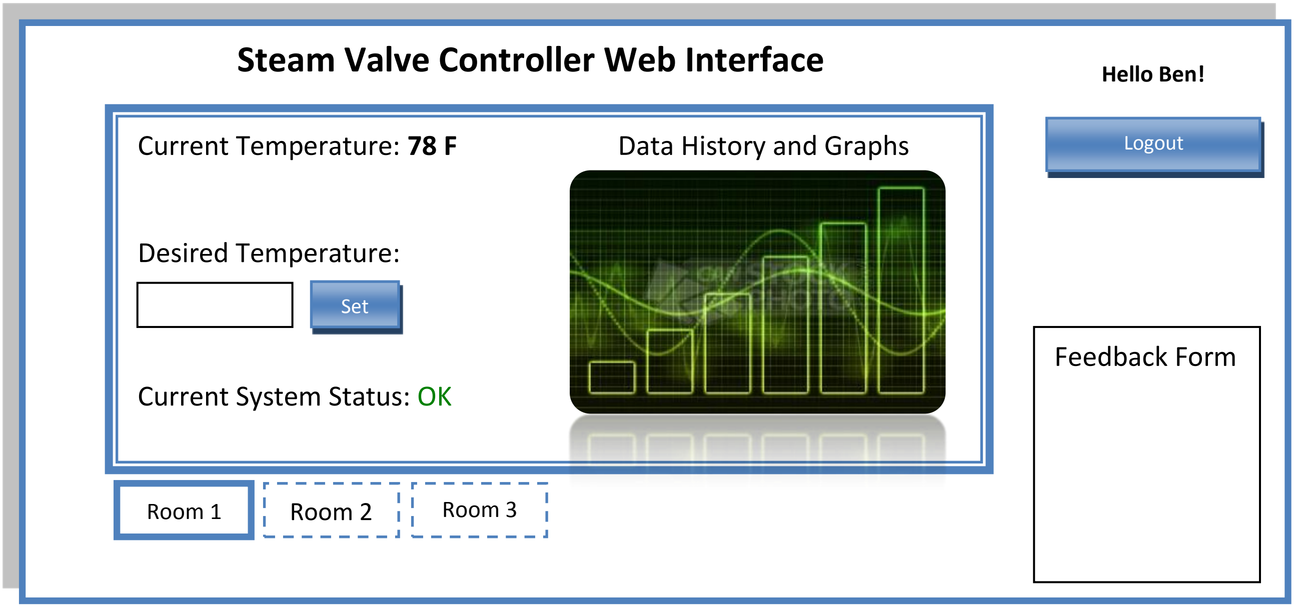

Database
Server for Website Interface
Internet
Steam Valve Controller with Motor
Admin
User
User
User
Room 1
Room 2
Room 3

Figure 52: Website interface functional diagram

The design below shows the overall layout of the home page of the website interface for a three room system for an average user.



Steam Valve Controller Web Interface

Hello Ben!

Current Temperature: **78 F**

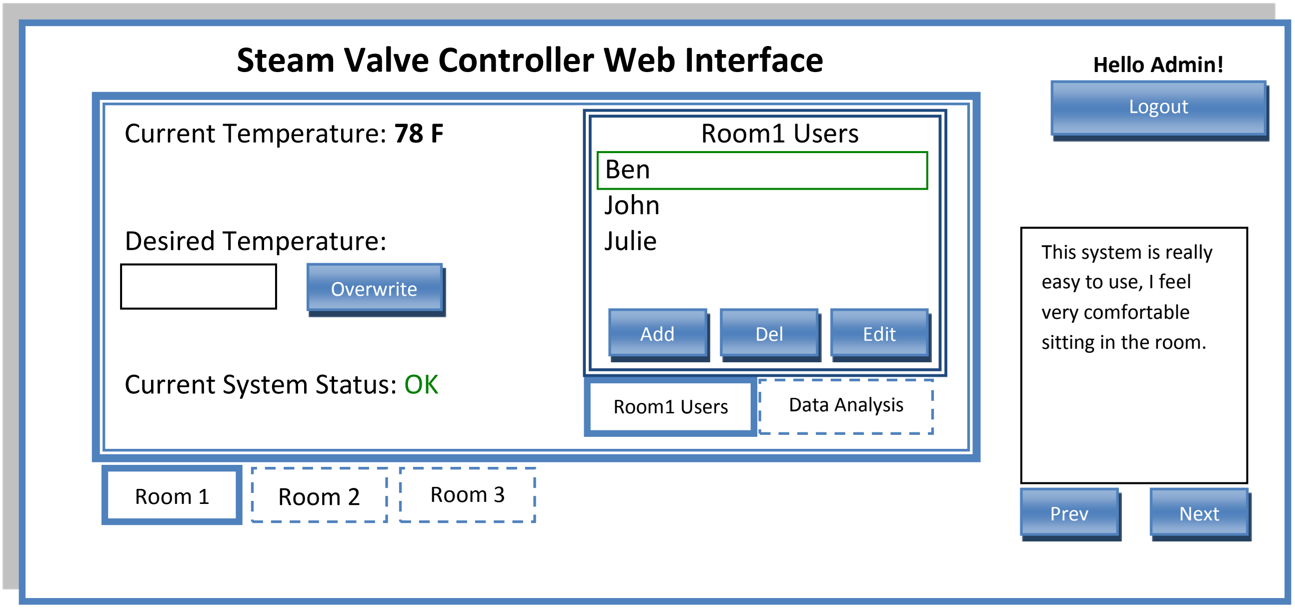
Desired Temperature:

Current System Status: OK

Feedback Form

Figure 53: Web user interface

The design below shows the overall layout of the home page of the website interface for a three room system for the admin.



Steam Valve Controller Web Interface

Hello Admin!

Current Temperature: **78 F**

Desired Temperature:

Current System Status: OK

Room1 Users

Ben
John
Julie

This system is really easy to use, I feel very comfortable sitting in the room.

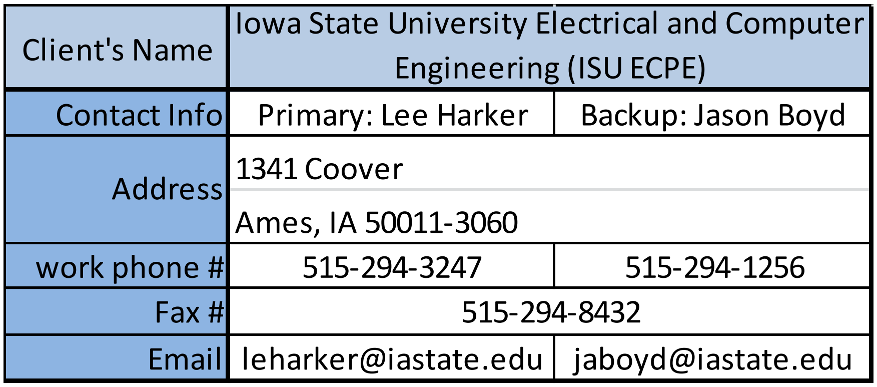
Figure 54: Web admin interface

PHP will be used to handle the front end of the website interface such as user authentication and the graphical user interface. The PHP code will then execute a script call with calls the Java JDBC code. The Java JDBC template code is used to connect to the database, which stores all the information about the steam control system and information about the users and admin.

Project Team Information

Should there be any questions or interested clients about our project, please use the following project team information to get in contact with us.

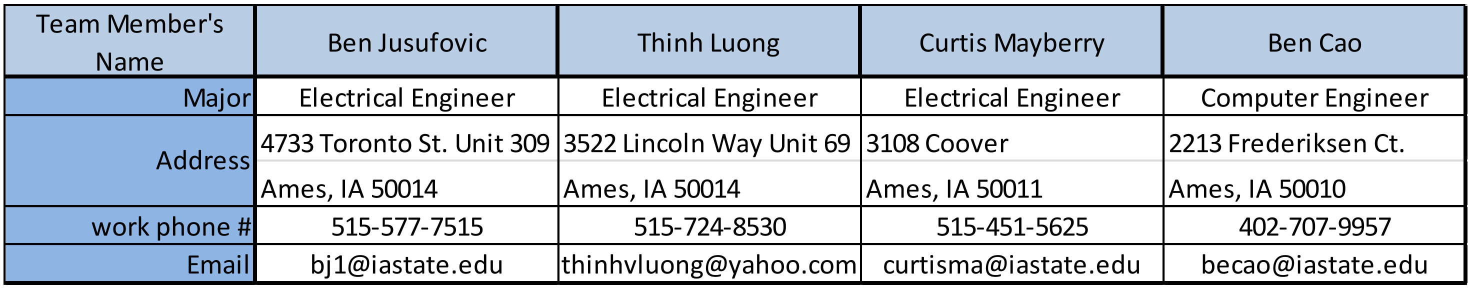
Client Information



Client's Name	Iowa State University Electrical and Computer Engineering (ISU ECPE)	
Contact Info	Primary: Lee Harker	Backup: Jason Boyd
Address	1341 Coover Ames, IA 50011-3060	
work phone #	515-294-3247	515-294-1256
Fax #	515-294-8432	
Email	leharker@iastate.edu	jaboyd@iastate.edu

Figure 55: Client Information

Student Team Information



Team Member's Name	Ben Jusufovic	Thinh Luong	Curtis Mayberry	Ben Cao
Major	Electrical Engineer	Electrical Engineer	Electrical Engineer	Computer Engineer
Address	4733 Toronto St. Unit 309 Ames, IA 50014	3522 Lincoln Way Unit 69 Ames, IA 50014	3108 Coover Ames, IA 50011	2213 Frederiksen Ct. Ames, IA 50010
work phone #	515-577-7515	515-724-8530	515-451-5625	402-707-9957
Email	bj1@iastate.edu	thinhvluong@yahoo.com	curtisma@iastate.edu	becao@iastate.edu

Figure 56: Team Information

Team website

http://seniord.ece.iastate.edu/may1119/index.htm

Closing Summary

Iowa State University buildings built prior to the late 1960's utilize steam valves and radiators to heat rooms. These heating systems link multiple rooms through steam pipes and consist of a single valve that controls the temperature heat output through radiators within each room. The user does not have knowledge of the magnitude of revolutions needed to accommodate a desired temperature within the room and causes over and under heating throughout the rooms. Since these heat systems consist of physical controls, Facilities Planning and Management does not have remote access to the system in order to regulate temperature in times of little to no occupancy. As a result, significant energy is lost during campus night hours and school breaks, consequently increasing energy bills.

In order to solve these issues, our group has proposed to perform a system level integration in which we will design a steam valve controller unit and a user interface unit. The steam valve controller unit will consist of a DC motor - used to rotate the steam valve, a microcontroller - used to run the control algorithm, a wireless transceiver - used to communicate to the user interface, and Ethernet connectivity – used to connect to the Iowa State network. The user interface will consist of a LCD display – human machine interface, push buttons – used to receive user input, a temperature sensor – used to record the room temperature, a wireless transceiver - used to communicate to the steam valve controller, and a microcontroller - used to control the user interface unit. Through design, we will integrate these components into an efficient temperature control system.

The end product will consist of two units: the user interface and the steam valve controller. The user interface will be a wall mountable unit similar to a thermostat. It will prompt for and accept temperature values from users. The unit will also be used as a means of sensing and recording current room temperature. It will communicate the current room temperature and user input temperature values to the steam valve controller unit. The controller unit will resemble a box structure and will be situated on top of the steam valve. It will run an algorithm based on received temperature values and adjust the steam valve appropriately through the DC motor. This system will allow user friendly temperature control and monitoring.

The only major issue that the group foresees is a shortened project deadline. Our product will be used throughout winter. Unfortunately, this is the only time that steam heat will be available. This means that our final prototype must be ready before the end of winter in order to finish final testing and assure that the product works as expected. Our group will have to put in extra effort in order to accommodate this change in schedule.

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Appendix A - Testing after final component selection

Motor driver test circuit

The following test circuit was recommended in the L298N datasheet for a bi-directional motor control circuit. We will construct the circuit and it will form the basis for our final circuit implementation.

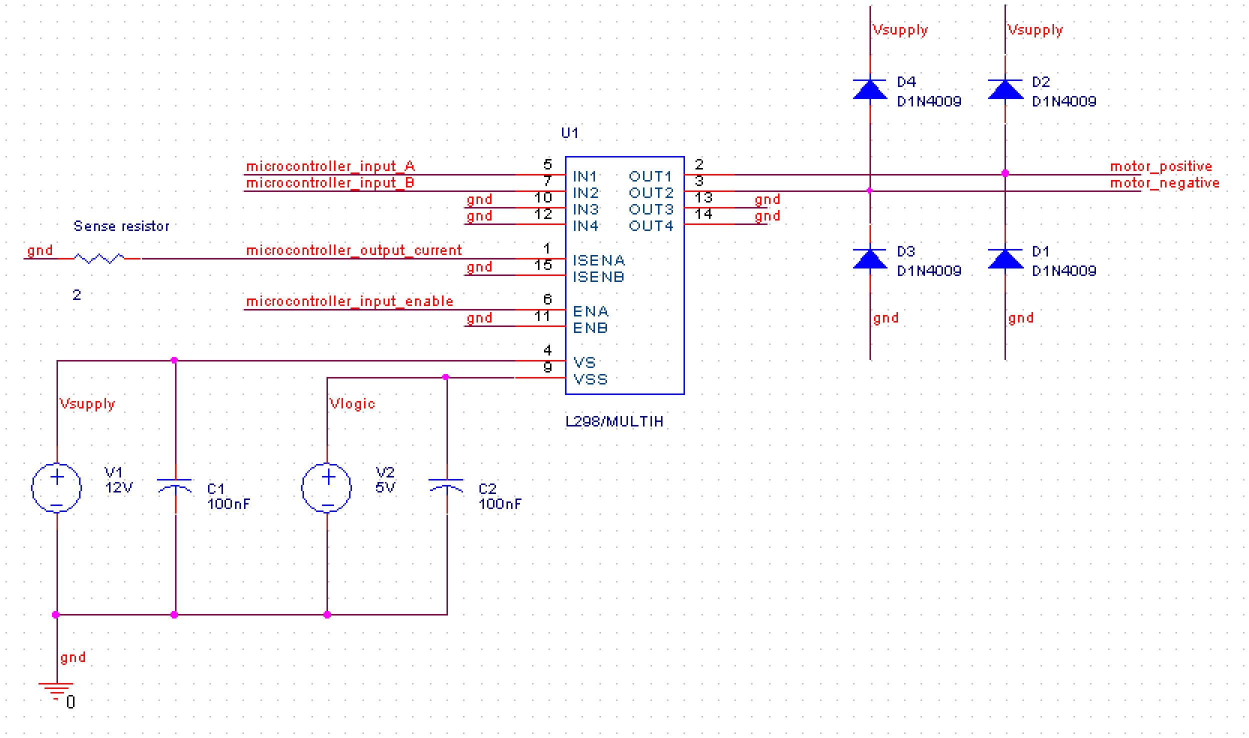

Figure 57: Motor driver test circuit

Note the flyback diodes configurations at the output. This is to prevent power generated by the rotating gear motor from going back into the L298N and damaging the device.

Magnetic shaft encoder circuit

The following test circuit was used to correctly receive the shaft encoder output.

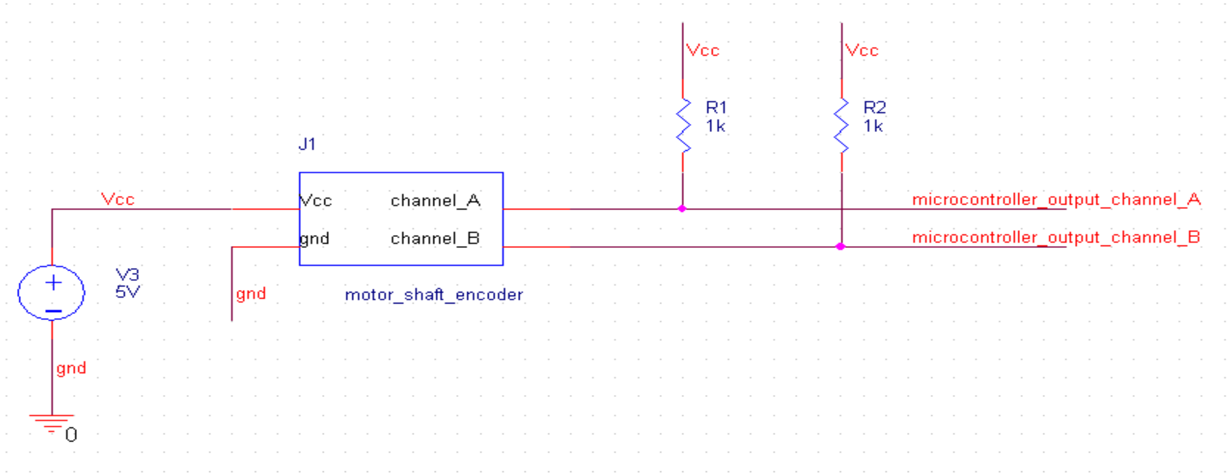

Figure 58: Shaft encoder test circuit schematic

Appendix B – PCB Schematic

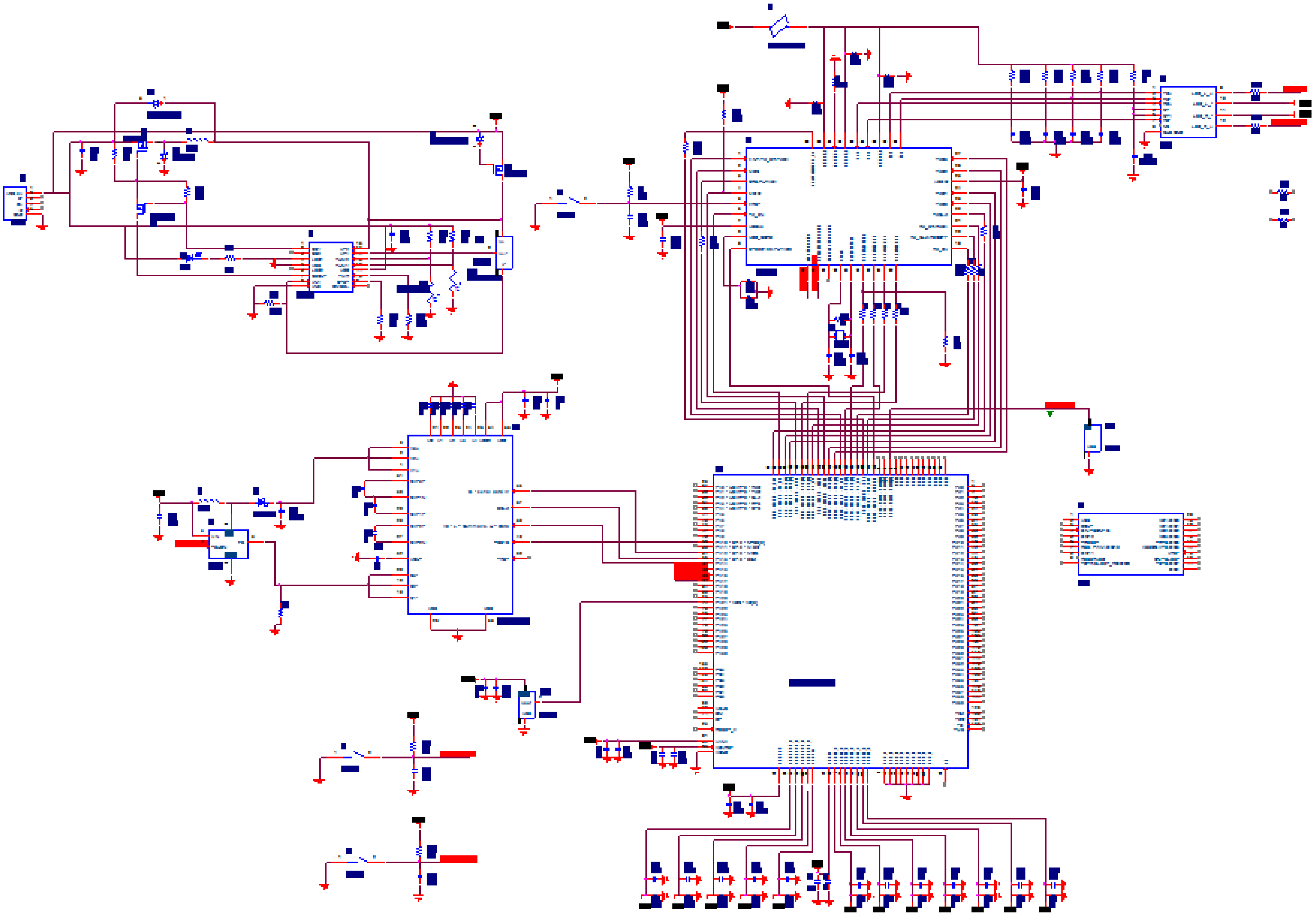

Figure 59: PCB schematic

Appendix C – PCB Bill of Materials

Bill Of Materials					
Distributor	Distributor PN	Distributor price	Part Reference	Tech	Value
Mouser	80-C0603C102J5G	0.05	C1	NPO	1n
Mouser	81-GRM219R61C475KE5D	0.05	C2	X7R	4.7u
Mouser	81-GCM1555C1H471JA6D	0.05	C3	NPO	470p
Mouser	81-GRM21R70J225KA01L	0.16	C4	X7R	2.2u
Mouser	81-GRM18R60J105KA01J	0.04	C5	X7R	1u
Mouser	81-GRM155R71H103KA8D	0.02	C6	X7R	10n
Mouser	81-GRM18R60J105KA01J	0.04	C7	X7R	1u
Mouser	81-GRM155R71H103KA8D	0.02	C8	X7R	10n
Mouser	81-GRM18R60J105KA01J	0.04	C9	X7R	1u
Mouser	81-GRM155R71H103KA8D	0.02	C10	X7R	10n
Mouser	81-GRM18R60J105KA01J	0.04	C11	X7R	1u
Mouser	81-GRM155R71H103KA8D	0.02	C12	X7R	10n
Mouser	81-GRM18R60J105KA01J	0.04	C13	X7R	1u
Mouser	81-GRM155R71H103KA8D	0.02	C14	X7R	10n
Mouser	81-GRM18R60J105KA01J	0.04	C15	X7R	1u
Mouser	81-GRM155R71H103KA8D	0.02	C16	X7R	10n
Mouser	81-GRM18R60J105KA01J	0.04	C17	X7R	1u
Mouser	81-GRM155R71H103KA8D	0.02	C18	X7R	10n
Mouser	81-GRM18R60J105KA01J	0.04	C19	X7R	1u
Mouser	81-GRM155R71H103KA8D	0.02	C20	X7R	10n
Mouser	81-GRM18R60J105KA01J	0.04	C21	X7R	1u
Mouser	81-GRM155R71H103KA8D	0.02	C22	X7R	10n
Mouser	81-GCM1555C1H471JA6D	0.05	C23	NPO	470p
Mouser	81-GRM21R70J225KA01L	0.16	C24	X7R	2.2u
Mouser	81-GCM1555C1H471JA6D	0.05	C25	NPO	470p
Mouser	81-GRM21R70J225KA01L	0.16	C26	X7R	2.2u
Mouser	81-GCM1555C1H471JA6D	0.05	C27	NPO	470p
Mouser	81-GRM21R70J225KA01L	0.16	C28	X7R	2.2u
Mouser	81-GCM1555C1H471JA6D	0.05	C29	NPO	470p

Mouser	81-GRM21R70J225KA01L	0.16	C30	X7R	2.2u
Mouser	81-GCM1555C1H471JA6D	0.05	C31	NPO	470p
Mouser	81-GRM21R70J225KA01L	0.16	C32	X7R	2.2u
Mouser	81-GRM18R60J105KA01J	0.04	C34	X7R	1u
Mouser	81-GRM155R71H103KA8D	0.02	C35	X7R	10n
Mouser	80-C0805C104K3R7210	0.02	C36	X7R	0.1u
Mouser	81-GRM219R61C475KE5D	0.05	C37	X7R	4.7 u
Mouser	81-GRM185C2A100JA01D	0.04	C38	X7R	10 pf
Mouser	81-GRM18B11H223KA01D	0.04	C39	X7R	0.022 uf
Mouser	81-GRM18R60J105KA01J	0.04	C40	X7R	1u
Mouser	81-GRM39C300J50	0.04	C41	X7R	30 pf
Mouser	80-C0805C104K3R7210	0.02	C42	X7R	0.1u
Mouser	80-C0805C104K3R7210	0.02	C43	X7R	0.1u
Mouser	80-C0805C104K3R7210	0.02	C44	X7R	0.1u
Mouser	80-C0805C104K3R7210	0.02	C45	X7R	0.1u
Mouser	80-C0805C104K3R7210	0.02	C46	X7R	0.1u
Mouser	81-GRM39C300J50	0.04	C47	X7R	30 pf
Mouser	81-GRM185C2A100JA01D	0.04	C48	X7R	10 pf
Mouser	81-GRM185C2A100JA01D	0.04	C49	X7R	10 pf
Mouser	81-GRM185C2A100JA01D	0.04	C50	X7R	10 pf
Mouser	80-C0805C104K3R7210	0.02	C51	X7R	0.1u
Mouser	81-GRM18R60J105KA01J	0.04	C52	X7R	1u
Mouser	81-GRM18R60J105KA01J	0.04	C53	X7R	1u
Mouser	81-GRM18R60J105KA01J	0.04	C54	X7R	1u
Mouser	81-GRM18R60J105KA01J	0.04	C55	X7R	1u
Mouser	81-GRM18R60J105KA01J	0.04	C56	X7R	1u
Mouser	81-GRM18R60J105KA01J	0.04	C57	X7R	1u
Mouser	81-GRM18R60J105KA01J	0.04	C58	X7R	1u
Mouser	81-GRM18R60J105KA01J	0.04	C59	X7R	1u
Mouser	81-GRM18R60J105KA01J	0.04	C60	X7R	1u
Mouser	81-GRM155R71H103KA8D	0.02	C61	X7R	10n
Mouser	81-GRM219R61C475KE5D	0.05	C62	X7R	4.7 u
Mouser	80-C0805C224K3R	0.11	C63	X7R	0.22 u
Mouser	80-C0805C104K3R7210	0.02	C64	X7R	0.1u
Mouser	81-GRM21BR61E106KA3L	0.15	C65	X7R	10u
Mouser	80-C0805C104K3R7210	0.02	C66	X7R	0.1u
Mouser	80-C0805C104K3R7210	0.02	C67	X7R	0.1u
Mouser	833-DL4151-TP	0.05	D1		MA739/TO
Mouser	828-OVS5MYBCR4	0.35	D2		LED

Mouser	512-MBRS320	0.44	D3		MBRS320
Mouser	833-MMBD4148-TP	0.08	D4		MMBD4148-TP
Mouser	625-P6SMB220A-E3	0.37	D5		P6SMB220A TVS
Mouser	673-J00-0061NL	3.9	J1		RJ45
Mouser	154-15322-E	0.51	J2		CON5
Mouser	506-FSM2JSMATR	0.43	J5		CON2A
Mouser	698-CAT4238TDG	1.6	J6		CON5
Mouser	700-DS2712E	5.13	J7		CON16
Mouser	506-FSM2JSMATR	0.43	J8		CON2A
Mouser	506-FSM2JSMATR	0.43	J9		CON2A
Mouser	815-ACML-0402H-750-T	0.04	L1		BEAD FERRITE
Mouser	652-SDR0703-470KL	0.53	L2		47uH
Mouser	652-SDR0703-470KL	0.53	L3		47uH
Mouser	522-ZXM61P02FTA	0.45	Q4		ZXM61P02
Mouser	522-ZXM62P02E6TA	1.14	Q5		ZXM62P02
Mouser	512-FDG312P	0.43	Q6		FDG312P
Mouser	301-100-RC	0.03	R1		100
Mouser	292-12.4K-RC	0.04	R2		12.4k
Mouser	304-10K-RC	0.04	R3		10k
Mouser	304-10K-RC	0.04	R4		10k
Mouser	301-100-RC	0.03	R5		100
Mouser	301-100-RC	0.03	R6		100
Mouser	301-100-RC	0.03	R7		100
Mouser	301-100-RC	0.03	R8		100
Mouser	301-100-RC	0.03	R9		100
Mouser	301-100-RC	0.03	R10		100
Mouser	301-100-RC	0.03	R11		100
Mouser	301-100-RC	0.03	R12		100
Mouser	301-100-RC	0.03	R13		100
Mouser	301-330-RC	0.03	R14		330
Mouser	301-330-RC	0.03	R15		330
Mouser	301-330-RC	0.03	R16		330
Mouser	301-330-RC	0.03	R17		330
Mouser	304-49.9-RC	0.04	R18		49.9
Mouser	304-49.9-RC	0.04	R19		49.9
Mouser	304-49.9-RC	0.04	R20		49.9
Mouser	304-49.9-RC	0.04	R21		49.9
Mouser	302-10-RC	0.04	R22		10
Mouser	304-10K-RC	0.04	R23		1.5k
Mouser	292-1.0M-RC	0.04	R24		1M
Mouser	71-CPF15R0000FHE14	0.37	R25		5

Mouser	71-WSL2010R1250FEB	0.81	R26		0.125
Mouser	304-10K-RC	0.04	R27		10k
Mouser	304-10K-RC	0.04	R28		10k
Mouser	304-10K-RC	0.04	R29		10k
Mouser	304-10K-RC	0.04	R30		10k
Mouser	292-75K-RC	0.04	R31		75k
Mouser	652-CR0603-JW-104GLF	0.02	R32		100k
Mouser	652-CR0603-JW-271GLF	0.02	R33		270
Mouser	304-10K-RC	0.04	R34		10k
Mouser	301-330-RC	0.03	R35		330
Mouser	81-NCP18XH103K03RB	0.14	RT1		THERMISTOR
Mouser	81-NCP18XH103K03RB	0.14	RT2		THERMISTOR
Mouser	556-AT32UC3A0128ALUT	10.18	U1		AT32UC3A-QFP144
Digi Key	TC1046VNBTRCT-ND	0.7	U2A		TC1046
Mouser	790-EADOGM128E6	18	U3		EA-DOGM128
Digi Key	XBP24-ACI-001	32	U4		XBEE
Mouser	12BH324A-GR	0.57	U6A		TC1046
Mouser	810-PS1240P02BT	0.39	U7A		Buzzer
Mouser	886-LAN8700C-AEZG	2.28	U8		LAN8700
Mouser	815-ABLS-25.0M-F-T	0.43	Y1		25MHz