Wireless Home Control System

Reimagine your home ™

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1 Executive Summary

The Wireless Home Control System is meant to be a solution for any homeowner to be able to remotely control core appliances of their home. The WHCS vision is to allow the user to control lights, outlets, doors, and sensors around their home. The system's design philosophy emphasizes ease of use, affordability, and effectiveness. An Android phone application developed for WHCS will allow users to monitor the state of the installed components and activate them remotely. A central base station equipped with a touch-enabled LCD will be present to allow the users to interact with the system without the need of a phone. Peripheral control modules will be installed into the targeted appliances such as lights, outlets, and doors for WHCS to control. Together the phone, base station, and peripheral control modules will constitute WHCS.

The implementation of such a system requires research in a myriad of fields to produce a full-fledged product. Android software development is the core for creating the users first impression with WHCS. Research must be conducted to conform to the design philosophies of the Android ecosystem. The alternative interface offered for WHCS will be the base station's display, as a result the best solution for a touch capable LCD will be examined. Communication devices will form the foundation for the wireless aspect of WHCS, thus an investigation into the advantages of different communication modules is required to realize the system. A network protocol will need to be planned out and implemented in order to form a unified system from the independent modules. The activation of appliances around the home requires high voltage control, so methodologies for properly harnessing the power provided by homes are a requirement. To extend upon harnessing the home's power, our individual control modules and base station's logic level voltage depend upon the creation of an efficient way to step down the high voltage supplied to the home. Efficient forms of rectification and power provision will need to be researched for WHCS to be self-sufficient. Important research and critical design decisions will go into the development of the printed circuit boards that will provide the foundation for all the hardware of WHCS.

Wireless Home Control System is a solution targeting the masses and designed by few. Naturally such a system will suffer from the constraints imposed upon the creators. Most prominent of all constraints are those stemming from economics. The development and production of WHCS will have to conform to the low budget available. Design decisions will be made to minimize overall cost of the system to satisfy this constraint. WHCS has the potential for mass implementation if user reception is positive so the design will adhere to manufacturing constraints. The parts used in the system will be chosen so that they are widely available. Our boards and parts will be designed so that they are easy to replicate and manufacture. With a product such as WHCS health and safety is clearly an issue. The system is meant to be installed inside the home where the user should feel at use with the system installed. Thus it is ethical for us to put effort into making the system safe to use. Things such as controlling the home's high voltage will have to be done in a safe manner. Security is another strong constraint attributed to products targeting the home. The system will be designed to maximize security for our users.

2 Project Description

2.1 Motivation

The goal of this project is to improve the quality of life for people in their homes. Imagine sitting on the couch at home about to watch a movie, but all the lights are on and it's a little warm inside. It is irksome to have to get up and turn off every individual light. With the technology existing today it is perfectly feasible to be able to turn off the lights and turn on a fan with a mobile phone. With the software available today it is even possible for this process to be initiated by voice. The problem that exists is these solutions lack mass implementation. By creating a wireless home control base station that a mobile phone could connect to these visions can be realized. The need to get up and physically interact with an appliance can be made a thing of the past.

We want to develop an easy to use system that allows people at their home to interact with their appliances without having to be in front of them. Our aim is for the solution to be reliable and low cost. The use case scenarios should be intuitive so that even someone who was just visiting could utilize the system. A person using WHCS should be able to turn on their lights or an outlet with the press of a button or with a voice command from their mobile phone. They should also be able to turn on their coffee pot from their phone when they first wake up. If someone knocks on the door the person should be able to unlock the door without having to get up. With the activation capabilities of WHCS there is an opportunity to utilize a foundation that can be expanded upon. We will have the infrastructure for integrating different types of sensors into the home to provide users with information about things like temperature or air quality.

2.2 Overview

The diagram pictured in Figure 1 shows the highest level overview of WHCS. When the user wants to begin interacting with WHCS he has the option of choosing to use a mobile phone or the included LCD screen. Both option will provide full capabilities for interacting with the system. The phone will be attached to the system through a BlueTooth connection that is created by the user in the WHCS application. Using the phone will be a more mobile and easy method for access because the LCD will be connected to the central component of WHCS, the base station. The base station will be the brains of WHCS. It will be the base station's job to take commands from the user and relay them to the endpoints, while also displaying the state of the system. The base station will have a list of endpoints, also called control modules, that can be targeted by the system. This list will be dynamic and allow for endpoints to be added or removed from the system during operation. Together the base station and the control modules will form a network through a home and will communicate wirelessly to one another through radio transceivers.

The control modules designed for WHCS will allow for all the activation of appliances around the house. These endpoints will be listening for commands from the base station via a radio transceiver. Each control module will be tailored for interacting with a certain device. There will be control modules for toggling outlets, toggling lights, unlocking the front door, and also for monitoring sensors. The control modules will be as similar as possible with a designated area that allows for assigning specific roles to the control modules.

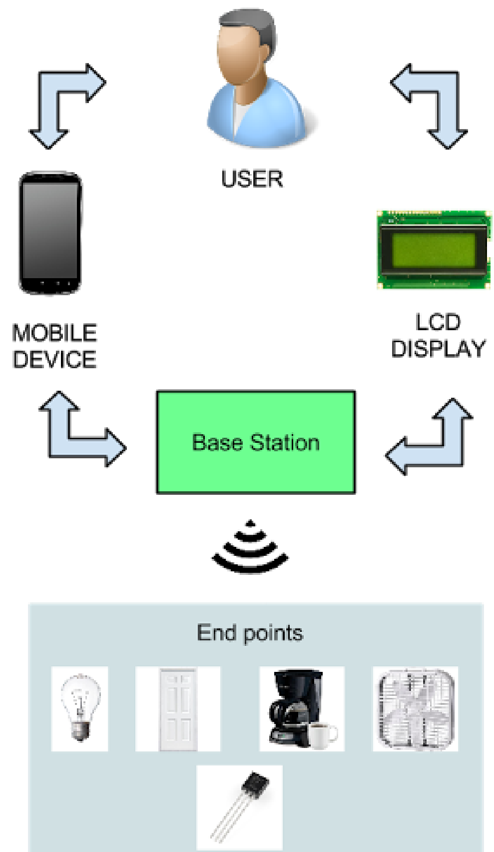

Figure 1: WHCS System Overview

2.3 Objectives

In order to enable homeowners to have the best experience with their new WHCS, we will explain our core project objectives. These describe what the end-users are be able to do with the system at a high level.

2.3.1 Voice Control

Voice control from a supported, BlueTooth enabled, Android device will allow the user to remotely activate any part of the home that is integrated with WHCS. This would include activating lights, unlocking doors, turning off and on appliances (by controlling their respective outlets), querying sensors, and any other home specific applications.[3]All of these *actions* and *targets* will be able to be used just from the user's voice. Voice actions will be specific to each target, but they will consist of verbs such as **turn**, **query**, **check**, **open**, **close**, and so on. The list of targets will directly correspond to the number of control modules listed in the home and their type. This will be explained in more detail in Section 4.

2.3.2 Light Activation

Through activating lights and querying their status remotely, a homeowner will no longer have to be present in the same room as the switch. By connecting lights to WHCS, they will become integrated in to the home network and not be isolated in each room of the home. With just a spoken command or a tap on their smartphone, lights will be controlled. By automating the process of toggling light switches, WHCS will have the ability to be smart about when they are ON or OFF, freeing the user from having to think about their state at all. In addition, lights, just like all of the other connected control modules in the home, will be able to be actuated on a specific schedule. This schedule can be designed by the homeowner to meet their daily lives or in a special circumstance, such as travel.

2.3.3 Outlet Activation

Lights aren't the only actionable thing in the home. There are a multitude of appliances throughout the home which could benefit from remote control. Some of these include coffee makers, toasters, or computers. If integrated with WHCS through outlet control, these appliances would be able to be apart of the home network. Imagine being able to start the morning coffee from the comfort of the bedroom. This would be possible with an appropriate coffee maker and WHCS outlet control. An added benefit from having outlets being automated is that there would be less draw from power leeching devices' power subsystems, which may be always-on.

2.3.4 Door Access

In addition to controlling home lights and various appliances, giving users remote control of their doors is a goal of WHCS. Through the use of an *electronic door strike*, we would provide specific control module the capability of locking and unlocking a door. This functionality would be demonstrated in Demo 10.5. WHCS sees door access as important for a home automation system to support because remote access, like a garage door, is simple and easy. We want to make opening *any* door simple and easy.

Unlike controlling appliances and reading sensors, correctly managing the operation of a safety-critical door must be handled with great care. Any flaw in the implementation of the WHCS network would leave a user's home vulnerable to outside attack. This is why any control module whose purpose is to control doors will support additional security features. These additional features will include mechanisms to prevent replay attacks (which garage doors are vulnerable to) and also prevent outside attackers from engaging the door opening mechanism just by sniffing traffic. For additional details on the security considerations of WHCS, please refer to Section 3.3.

[3] WHCS is an extensible system. Control modules are built with a plugin-like interface, allowing for intrepid home owners to have a fully custom home. This combined with the control module's free breadboard area, new applications may be created.

2.3.5 Data Collection

In order to give users a broad overview of their home's state, WHCS supports the collection of data from *arbitrary* sensors. Data collected can include temperature, humidity, light level, sound levels, and so on. Each home may have sensors throughout collecting various data that the homeowner deems useful. The sensor integration with WHCS would be transparent to the user. All they would see would be the list of sensors and the corresponding values. WHCS's pluggable control module's would be tailored to each sensor or set of sensors, which would relay their data back to the base station. This is illustrated in Figure 2. The base station would support queries from the LCD interface and simultaneously from a connected phone.

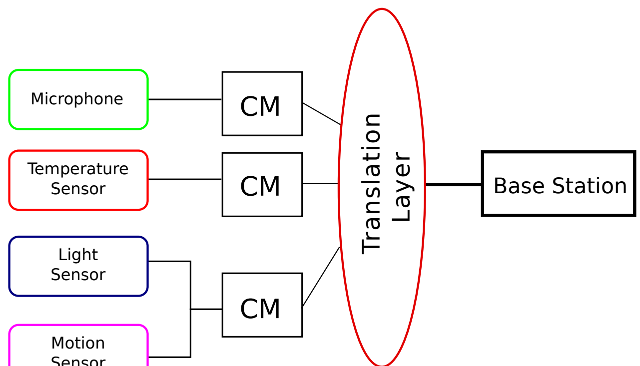

Figure 2: A illustration showing the translation of many different sensor nodes to WHCS' protocol

Beyond home sensors, all of the other controllable objects in the WHCS would have metadata being collected about them at all times. This extra metadata would include **connection status** and **power status**. See Section 5.1.4 for a more detailed description of the supported network packets and the type of fields they support.

All of this raw data being collected could be displayed to the user in the form of graphs and tables. It would also serve as the basis for a set of descriptive statistics for display to the user.

2.4 Requirements and Specifications

2.5 Research of Related Products

2.5.1 Z-Wave

2.5.2 Belkin

2.5.3 Apple HomeKit

2.5.4 Nest Labs

Unlike the previous companies, Nest Labs is quite new, but has certainly claimed its space in the smart home market with its smart Nest Thermostat. Their other product, the Nest Protect, a smart smoke and CO_2 detector, integrates smoothly with the thermostat allowing for remote monitoring and control of the home. For their thermostat, the primary goal is to have a smart learning thermostat that aims to save energy in the home. By keeping temperatures at energy-saving levels when no one through the use of a motion sensor and learning algorithms, one of the most expensive home energy costs can be reduced.

In terms of administration, Nest has a online web interface and a mobile app that will display all of the networked devices, allowing for a highly connected experience. Change your temperature from your warm bed or before you even get home!

Nest Labs was recently purchased by Google for $3.2 billion dollars, which certainly gives the company a powerful position in the market. One of Nest's goals is to have a *platform* for other companies and developers to create new products that *Work with Nest* ^{TM}. This strategy is clever as now the success of the company will grow with every new developer who chooses to integrate their products with the Nest suite. Customers will see the multitude of devices that work with Nest and realize that they can "harness the future today." Quite a solid business model. Coming in at $249, the thermostat might be a tough sell for typical home owners who already have a working, yet "dumb", thermostat.

2.5.5 X10

3 Realistic Design Constraints

3.1 Economic Factors

3.2 Time Limitations

3.2.1 Project Ramp-up

3.2.2 Summer Semester

3.3 Safety and Security

The safety and security of WHCS is primary constraint of the project. Due to the integration with home, especially access control systems, WHCS must not negatively affect home security. Additionally, as WHCS is in control of large currents involving light control and outlet control, great care must be taken to design circuits and software to prevent fires and misbehavior. If for instance, we decided to control a light that exceeded the rating of one of the control relays, then this could be a fire hazard. Also, in terms of door control, if the mechanism for controlling the door were to fall in to the hands of a burglar or fail completely this would present a critical safety and security issue.

For example, there is a trade-off that needs to be made for controlling a door with an electronic strike. Electronic strikes come in two main flavors: normally opened (NO) and normally closed (NC). NO favors security by *failing-secure*, meaning the lock will not be openable if in the event of a power loss. NC on the other hand will *fail-safe*, meaning the lock will be openable without power applied. This consideration should be based around local fire code and depending on the type of door and handle used. We explain our decision to go with a NO type electronic strike in Section 5.8.4.

In general, some principals for making sure that safety and security problems are taken in to consideration are

1. Analyze potential problem areas
2. Develop solutions for problem areas
3. Anticipate failures and handle them accordingly

Through premptive *analysis*, we may determine problem areas. We will *develop* solutions for these problems, consisting of a description of the problem, its potential impact, what area does it impact, and what we plan to do to address it. Finally, we will *anticipate* failures and build in the developed solutions directly in to our design. These solutions may be in the form of warning labels (Ex. DO NOT EXCEED 12V 10A) and software checks.

3.4 Spectrum Considerations

For WHCS we will need to provide over the air communication between the android device to the base station and between the base station and the control modules. Out of the frequency bands that the FCC has marked as unlicensed we decided to use the band that includes 2.4 GHz. Although there are other unlicensed bands that could have been used such as the 900MHz band and the 5GHz band, 2.4GHz provides the best solution. The higher the frequency the shorter the range yet the better the data rate and the smaller the device. The main reason why 2.4GHz was chosen is because it is a happy median of good range and acceptable data rates. Unfortunately because 2.4GHz is such a good frequency to operate at it also has a lot of interference from other devices that operate at this same frequency. However interference will happen from whatever frequency band that is chosen, and this issue wasn't enough of a problem for our design to deter us from using the 2.4GHz band. Both the NRF chip and the Bluetooth chip operate within this band.

4 System Design

4.1 Base Station

4.2 Control Module

4.3 BlueTooth Capable Phone

5 Hardware and Software Design

5.1 Radio Transceiver

For the radio transceiver of WHCS the chip that we decided to use is Nordic Semiconductor's NRF24L01+. This chip meets all the requirements that we set for our radio transceiver. The NRF is also a very popular chip that is easy to find and rarely out of stock. This is a benefit to the manufacturability of WHCS because NRFs are cheap and easy to buy in bulk. Alternatively we could have chosen to use an XBee radio device which implements the zigbee 802.15.4 IEEE standard, however we did not see the need for this. XBee devices are also more expensive than the NRF chips that we have decided to utilize.

5.1.1 Operating Principles and Usability of NRF24L01+

The NRF24L01+ is a radio transceiver that operates in the ISM (Industrial, Scientific, and Medical) radio band. The range of channels for the NRF is 2.4GHz to 2.527 GHz, however because the designated ISM band that we are using only ranges from 2.4GHz to 2.5GHz we will not be able to use all of the NRF's available channels. With the NRF we are capable of sending payloads with a maximum size of 32 bytes per transmission from module to module. We will be able to change the data length from 1 to 32 bytes in order to find the optimal mix between reliability and speed. Every NRF chip has the ability to simultaneously store

1 transmission address and 6 receiving addresses. The first receiving address is utilized if the auto-acknowledgement feature is enabled, so effectively there are 5 receiving addresses. This capability gives us flexibility for implementing our network because we make decisions such as having a dedicated address to each node in the network as well as an address for broadcasts of certain types. The addresses of the NRF are 5 bytes wide so we will be able to have many NRF modules within the network. A very useful feature of the NRF is the ability to enable auto-acknowledgement. When this feature is activated the receipt of a transmission from one NRF to the other is auto-acked without the need from any upper level software. This simplifies the work necessary for creating our own network of NRF chips. We will be able to confirm the receipt of data therefore increasing reliability. This auto-ack also allows the NRF to perform retries up to a given limit, so just in case there is noise during the transmission the NRF will repeatedly try to transmit again. The NRF also allows for low power mode and long range mode. For WHCS we will be able to tweak whether or not to use long range mode or not depending on the performance of the system within its environment.

The NRF requires 3.3v of electricity to operate so all parts of WHCS will require a 3.3v line. The datasheet lists the current consumption while in receive mode as 18mA. This will be the most common mode for the NRF chips present in WHCS so they can be ready to receive commands at any time. The chip receives commands from a microcontroller through SPI (Serial Peripheral Interface). This is great because the NRF design philosophy fits perfectly with our microcontroller based base station and control modules. Beside the standard MOSI, MISO, and SCK for SPI, the NRF also has a csn pin for telling it to receive commands, ce pin for telling to to transmit or receive at that moment, and an interrupt pin for notifying the microcontroller of important situations. The csn pin will allow the SPI bus to be shared with other components such as the LCD being used for the base station. The interrupt wire pin can be monitored in order to listen for data received, data sent, and data failed to send notifications. In total the NRF will take up 6 pins whilst three of the pins will be shareable with other SPI components.

5.1.2 Driver Use Case

The NRF chip that we have decided to use for communication in WHCS will need to have a driver written for it. This will help keep the way we interface with the NRF consistent and will provide clean code. All of the network code that we write for the base station and the control modules will be relying on the integrity of the NRF driver that we write. The driver provides the foundation and if it is not reliable then none of the code we write for our system will be reliable. The focus for the development of the NRF driver is elegance. We want everything the NRF driver offers to be simple yet accomplish everything necessary. We have developed the use case diagram pictured in Figure 3 as a guideline for the development of the NRF driver. The NRF driver should provide the functionality included in the use case diagram in an easy to use format. These will be the most common uses of the NRF.

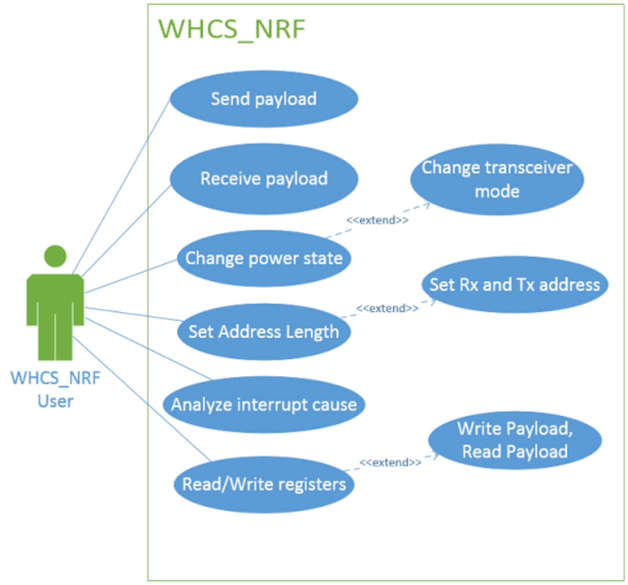

Figure 3: NRF Driver Use-case Diagram

The core use of the NRF driver is transmitting and receiving payloads. Every other use case is a supporting role for the final goal of transmission. The basis of the driver will be reading and writing registers. Everything will build off of this capability, especially reading and writing the payload for transmission. Other use cases such as changing power mode, checking the status of the chip, and changing from a transmitter to a receiver will be special forms of writing to a register. Thus reading and writing to registers is a use of the driver, however it will be abstracted in a way that provides ease of use. A user of the NRF driver will spend most of the time setting addresses, writing payloads, transmitting payloads, and analyzing interrupts. These use cases need to be implemented perfectly to provide a strong foundation for the networking of WHCS.

5.1.3 Driver Class Diagram

It was decided that the best design approach for implementing the NRF driver was as a class in C++. We will be using Atmel ATMega microcontrollers in WHCS so C++ is supported as a development language. Using C++ allows us to create a class that can leverage object oriented programming techniques such as encapsulation. The class diagram for the driver is shown in Figure 4. Primitive functions such as ReadByte and WriteByte can be hidden from a user while PowerUp will be exposed as a public function. Using C++ also gives us the ability to use a constructor when using the WHCSNrf class, and in this constructor we can assign the only thing varying between uses of the NRF, the chip enable pin and the chip select not pin. Assigning the ce pin and the csn pin are the first step of using the NRF driver. Any communication between the microcontroller and the NRF will rely on the proper assignment of these pins.

Figure 4: NRF Class Diagram

Usage of the NRF driver will involve first constructing the class by telling the microcontroller which pins the NRF is connected to. Then the user will be doing everything necessary to customize the way that data is transmitted and received. The driver exposes the common settings in an easy to access manner. Enabling things such as auto-acknowledgement and the number of retries for the transceiver can be done with the call of a function with simple parameters. Setting the address for receiving and transmitting data can be done in one line of code. The SetTxAddr function will be one of the most utilized function for an NRF involved in a network constantly sending payloads to other chips. A typical use will involve powering up the NRF with the PowerUp call, setting the transmission address, writing a payload, and then transmitting a payload. With this driver, the user does not need to know the registers involved with the NRF. The hardware interactions with the chip are all abstracted away.

5.1.4 Network Library

5.2 Microcontrollers

For the proper operation of WHCS microcontrollers will need to be installed into all of the control modules as well as the base station. This meant research was needed to choose what the best microcontroller for each of the modules was. The base station is a bit more hefty than the control modules so the design considerations are different for the two. The first step was to figure out what family of microcontrollers to use.

5.2.1 Microcontroller Brand

Choosing the microcontroller brand would set the path for all the development that we do with the microcontroller. Every other choice would stem from this decision so we wanted to make a smart choice. We weighed out the documentation, support, ease of acquisition, ease of use, and community for the brands that we considered. Our initial choice was Texas Instruments because of the use of the MSP430 launchpad board in the UCF curriculum. The fact that using the MSP430 was required in EEL 4742 (Embedded Systems) meant that everyone was already at least somewhat familiar with it. The familiarity factor was a plus for the MSP, and we all knew that T.I. has very good, albeit lengthy, documentation for their chips. A quick look at digikey showed that MSP430 microcontroller chips were well in stock so there would be no problem acquiring them if they were the chip that we wanted to use. The thing that we were unsure about with using Texas Instruments chips was the community surrounding the brand. For example if we encountered a problem rewriting a fuse on the microcontroller would we be able to find a forum of people who knew how to solve the problem, and things of that nature.

While we researched Texas Instruments based microcontrollers we also researched the Atmel brand. We knew Atmel is very popular especially because they produce the chip used on the Arduino development boards. We checked how the Atmel chips were documented by looking at the datasheet for the Atmega 88, and were pleased with how well things were laid out. Digikey had most of the common brands of Atmel chips in stock so acquisition would be no problem. We didn't feel the need to consider any other brands because we felt that between the two choices we looked into they could both suit our needs. Atmel offered chips and brand support similar to that of Texas Instruments, so for whatever kind of chip we required we could use Atmel or T.I. For us the choice came down to how prominent the communities for the two brands are. Ultimately we decided that the Atmel brand had a very pervasive community that was sure to aid us in our utilization of any chips produced by the company. While the MSP430 was familiar to all of us the Texas Instruments chips did not seem as broadly used across the open source populus. So our final decision was to use the Atmel brand of microcontrollers for WHCS.

5.2.2 Base Station Microcontroller

The base station is the center of operations for WHCS so it needs the most computing power. It has the most data structures to take care of, the most commands to process, and the longest compiled program. The microcontroller for the base station also needs to be able to connect to the LCD screen, the radio transceiver, and BlueTooth transceiver all at the same time. So taking all these things into consideration for choosing the microcontroller was important. We needed a large amount of pins to interface with all the peripherals, especially because we knew we wanted a parallel interface LCD. A large amount of flash memory was also a trait that we looked for since we knew the base station would be doing a lot, thus making its program long. The first big decision was whether to use an ARM based microcontroller for our base station since it was the brains of the system. ARM microcontrollers have much higher processing power, but also introduce complexity. Many ARM microcontrollers don't have on board flash memory so that is an added layer of design that is needed to get the unit working. After considering the processing necessary in the base station and the bandwidth of the network in WHCS we realized that an ARM based microcontroller would not be necessary. There was not enough data to be processed to warrant the use of an ARM microcontroller. Using an ARM unit would introduce design complexity for a solution that could be attained through easier means.

Eventually our research efforts landed us upon the Atmega series of Atmel microcontrollers. These microcontrollers are often thought of as the flagship Atmel chips in the DIY community and they did seem highly capable. The chips were cheap, had plenty of pins, plenty of on-chip peripheral support such as the UART, were easy to program, and were highly available. After browsing the Atmega series of chips we narrowed down the chip that we would be using for the base station to the three chips listed in Table 1. The table shows that the lowest maximum operating frequency between the three is 16 MHz which is more than capable of powering the low bandwidth network of WHCS. 16 MHz is enough to handle communication, the LCD display and interrupt vectors, so all the chips are viable options in that feature. The 8 KB of flash memory was low compared to the 32 KB offered by the other two so we actually took that chip out of the running when we considered that the base station would have a large routine. When we were down to choosing between the Atmega328 and the Atmega32A we realized that the Atmega32A was actually the only option between the two chips that would work. The reason for this was the number of I/O pins. We had picked the LCD, radio transceiver, and BlueTooth chip that we would be using and the Atmega32A was the only chip with enough I/O pins to support all the peripherals. Our final decision was to use the Atmega32A as the microcontroller for the base station.

Atmega MCU	Flash Memory (KB)	Max I/O Pins	Max freq. (MHz)
Atmega88	8	23	20
Atmega328	32	23	20
Atmega32A	32	32	16

Table 1: comparison of ATMega chips

After we had decided to use the Atmega32A as the microcontroller for the base station there were still some things that needed researching to make it usable. The main issue was disabling the JTAG interface on port C to make the pins usable as general I/O. After researching the data sheet and the community forums we found that to be able to use port C pins as GPIO the JTAG fuse must be disabled. Otherwise setting these pins on port C to high or low will have no effect.

5.2.3 Control Module

5.2.4 Development Environment

5.2.5 Programming

5.2.6 External Oscillator

5.3 BlueTooth Chip

The BlueTooth device for WHCS will enable the base station to communicate with the mobile phone controller. Our guidelines for choosing a BlueTooth device included ease of use, reliability, size, cost, availability, and documentation. There were a multitude of BlueTooth devices to choose from. Special attention was paid to how well the BlueTooth device could connect to a microcontroller UART. Two BlueTooth devices, the HC-05 and the RN-41, showed the most promise. Our research of the two devices showed that they both had their advantages and either one could be implemented in our design. After careful consideration we chose to utilize the HC-05 in our design, however the RN-41 could still replace the HC-05 if necessary.

An important factor for considering the BlueTooth devices was if the internal settings of the BlueTooth devices could be changed and if possible how. Such internal settings include things such as the device's BlueTooth name, baud rate, and passcode. These things need to be changed from their default settings or else many BlueTooth devices would have similar names, and they would all have default passcodes. We want to implement good security into WHCS so we need to be able to change the default passcode for the BlueTooth device. Also the baud rate is usually low in BlueTooth devices by default, which can be bumped up depending on the microcontroller being used. A BlueTooth device that could not be programmed easily was not an option.

5.3.1 RN-41

The RN-41 is a BlueTooth module designed by Microchip. This module is designed to be an all inclusive solution for embedded BlueTooth. It is clear that a lot of design went into this chip because it is very high quality and the data sheet is very thorough. Along with the high quality of the module comes the high cost. Of the two considered BlueTooth modules the RN-41 was much more expensive with a price of $21.74 from Microchip. The high price tag makes it a less appealing option out of the BlueTooth devices because they are effectively accomplishing the same thing. The module itself appears well designed visually and it has dimensions of 25.8x13.2mm so it is not obtrusive and could fit well onto a PCB. There are 24 pins on this device and the datasheet gives the dimensions down to the pin spacing allowing for easy PCB layout design. The RN-41 makes communicating with microcontroller UARTs easy by simplifying RS-232 down to the Rx and Tx wires. This means the only connections necessary for using the RN-41 with a microcontroller are power, ground, Rx, and Tx. The microcontroller's that we have decided to use include Rx and Tx pins that hook up directly to the RN-41. From the microcontroller's point of view the BlueTooth device does not even exist. The RN-41 acts as a transparent man-in-the middle and simply relays messages from a BlueTooth device to the microcontroller and vice versa. This is perfect for our design because the RN-41 could just be plug and play. With an advertised 100 meter transmission range the RN-41 meets the requirements we set for distance of BlueTooth reception. According to the datasheet the RN-41 has a maximum baud rate of 921K which means it goes above and beyond the transmission rates necessary for communicating between the mobile device and the base station.

The RN-41 has a manageable means of programming the internal settings. When the RN-41 is on, sending "$$$" over the UART lines puts the chip into command mode. From here there are a list of commands that can be passed in order to inquire or manipulate the state of the module. There are advantages and disadvantages to this approach. It is great that it is easy to program the RN-41 just by passing certain data while it is wired normally, however in the event that the sequence "$$$" was ever passed during operation it could throw off the whole system. This is not a terrible thing but it is worthy of consideration.

5.3.2 HC-05

The HC-05 is a BlueTooth module that shares many similarities with the RN-41. It is of comparable size to the RN-41 with dimensions of 27x13mm. HC-05 modules are also commonly sold along with a breakout board with male headers. This makes it an option to have the PCB include female headers and use them for installing the HC-05. Our intention for the base station containing the BlueTooth module is to have the PCB board hidden, so using female headers for plugging in the HC-05 to the PCB is a viable option. The module is advertised as a low power class 2 BlueTooth device with power consumption for communication listed at 8 mA. This is lower power consumption than the RN-41. The max signal range is not listed in the data sheet, however we have tested this chip and have achieved a signal range of more than 50m which is more than enough for what we desired in our BlueTooth chip. Just like the RN-41 the HC-05 communicates to microcontrollers by simplifying RS-232 and only using the Rx and Tx pin. The maximum supported baud rate is 460800 which will allow for very fast data transfer and will exceed the needs of communication speeds in our system.

The HC-05 comes with default settings similar to most BlueTooth modules. The default baud rate is 9600 and the default passcode is 1234. In order to change this the module must be accessed in AT mode. AT mode is entered by utilizing pin 11 "key" on the HC-05. When this pin is held high, the module enters AT mode on startup and is ready to take commands. This means that whenever we want to program the BlueTooth module we will need to use a microcontroller with a UART connection to a terminal as well as a UART connection to the HC-05. This will require the implementation of a software Rx and Tx pin. This will only need to be done once because once the BlueTooth module has been programmed it retains that configuration. The requirement of holding the key pin high during startup of the module eliminates the danger of entering the programming mode during normal operation.

For WHCS we have decided to use the HC-05 as our BlueTooth module instead of the RN-41. Table 2 shows highlights of the features of each BlueTooth module that led to the decision. The main factors deciding this were the cheaper price of the HC-05 and the fact that they both accomplish the same thing. The table shows clearly that the HC-05 is a much more affordable option. The two chips were comparable in size, features, wiring, layout, and usability however at the price of $6.64 the HC-05 cost less than half of the RN-41. The RN-41 is the second best choice and can serve as a fallback if HC-05 chips went out of stock or an unforeseen circumstance occurred.

	Cost	**Range (meters)**	**Breakout Option**	**Configurable**	**Size**
RN-41	$21.70	100	No	Yes	25.8x13.2mm
HC-05	$6.64	50+	Yes	Yes	27x13mm

Table 2: comparison of the BlueTooth chips

5.4 LCD

Being able to interface with WHCS like a normal wall thermostat is one of our project goals. Having a centralized display that can quickly display the most important information for homeowners would be step up from traditional “dumb” thermostats. With a simple LCD combined with a touchscreen, users would have a way to control and query their home without having to find their phone.

To make this a reality, we have chosen the versatile, premade, and well supported Adafruit 2.8” TFT LCD[4] with a resistive touchscreen. Internally, the display is driven by the feature-rich ILI9341 chipset. This chip is specifically created for a 240x320 pixel LCD with a focus on small, power-conscious mobile devices. Another reason we chose to buy this from Adafruit and not integrate the chip directly is due to the complexity of the design. Also, with the abstracted product, there are plenty of usage examples and Adafruit’s excellent technical documentation. This combined with Adafruit’s libraries, assure that integrating the LCD will be straight forward. The one issue with this solution is with the ILI9341 driver code: it was written to target the Arduino platform. Now, the Arduino platform is fairly close to bare AVR, minus the remapped pin numbers and some support libraries, so porting Adafruit’s library would be a feasible solution. Our plan is to use the existing driver along with the chip datasheet to create a library specific to our needs. That way we get full control over the port placement and the experience of creating an LCD driver.

5.4.1 Capabilities

In terms of capabilities, we have summarized the main features of the LCD module in Table 3

[4] https://www.adafruit.com/products/1770

Specification	Description
Resolution	240x360
Colors	262K @ 18bits, 65K @ 16bits
Voltage Input	3.3 - 5V
Weight	40 grams
Dimensions (LCD itself)	2.8" diagonal
MCU Interface	Multiple. See Section 5.4.2
Touchscreen technology	Resistive (one finger)

Table 3: a brief summary of the pertinent features of the LCD module

These features are more than sufficient for out application as most of the drawing we will be doing will be non-realtime. Nearly all of the displayed information will be text and UI element, which don't change often. For an overview of our UI elements, see Section 5.4.5.

One of the beneficial features of the LCD is that it gives developers a choice of which interface to use. The broken out interfaces are 4-bit SPI and 8-bit parallel. For prototyping, we used the low pin count SPI interface, but for our final design, we will be using the 8-bit interface to avoid having to wait for lengthy SPI transfers. Also, our NRF radio will be using the SPI bus, which should have priority over that channel. You may view a high level overview of the LCD module in Figure 5.

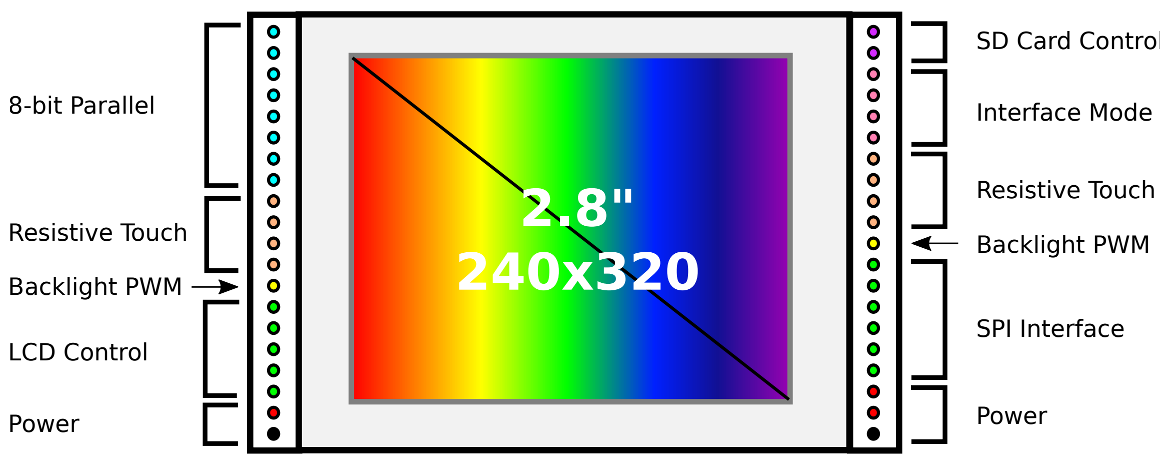

Figure 5: a high level outline of the LCD pin configuration and specifications

Another feature of Adafruit's module is the resistive touchscreen present on top of the LCD. With this, we don't just have to display information about WHCS, we can receive commands as well! Using this simple interface, we plan on creating a featureful UI library to communicate up-to-date information about the home while allowing for user control. The specific interface for the touchscreen requires 4 pins, 2 of which must be connected to the MCU's Analog to Digital Converter. By reading the resistance of the touchscreen, we would be able to calculate the position of a single finger.

Finally, one extra component on the LCD module is an SD card slot. We are free to read and write directly to this card to store large images, such as logos for display on the LCD.

We plan on storing at least our logo, but we may also store fancy UI badges such as arrows ($\leftarrow$, $\rightarrow$), X's ($\otimes$), checkboxes (☑), and anything else we can think of.

5.4.2 ILI9341 Driver

In order to perform the required operations for drawing pixels to the LCD, we need a robust driver to manage the state of the ILI9341 chip. This driver will have to implement primitives for choosing a position to draw and the ability to fill pixels.

5.4.2.1 Choosing where to draw The ILI9341 works like many chips in which it has a command set for controlling display parameters. One of these commands will set the window in which pixel data is drawn. Before a batch drawing operation, a window is selected by specifying the column and page addresses. These are set using the **Column Address Set (0x2A)** and the **Page Address Set (0x2B)** commands. From this point, the RAMWR command is send followed by N different 16-bit pixel colors. This scheme of setting the window and filling the pixels is why the graphics transfers end up being so slow, which is discussed more in Section 5.4.2.3.

5.4.2.2 LCD State Management Beyond just drawing pixels, the LCD module has a wide variety of bonus features that could assist us in making a fully-featured interface. One of these is vertical scrolling, which could enable us to cheaply draw familiar UI elements, such as list views. The most intensive state management comes from the early initialization of the LCD module straight from power on. This requires a long incantation of LCD commands with equally archaic parameters in order to reach the initialized zen. Luckily, there are multiple examples of slightly different LCD initialization sequences online for reference. In terms of power management, the LCD controller provides a command set to set the power mode. Although, the base station will be on wall power, being able to dim the screen and save energy would be a useful feature.

5.4.2.3 LCD Performance Due to the real-time nature of microcontrollers, everything must be juggled as quickly as possible in order to have a good responsive design. Imagine a user touch kicking off a set of expensive UI redrawing operations. Well, a WHCS control module has just sent its latest state to the base station, but it cannot be serviced due to the drawing operation! This is a common theme throughout real time environments, so much so that highly specialized Real Time Operating Systems have been created to provide *assurance* that some operation/action will complete within a specified amount of time. We don't have that luxury – instead we must consider performance before we hit any performance walls.

The slowest part about managing the LCD are the synchronous transfer of commands and pixel data between the MCU and the graphics controller. Each ILI9341 command is 8-bits and before any pixel operation the CAS and PAS commands need to be set. These commands have two 16-bit arguments *each*! For settting just one arbitrary pixel 104 bits would need to be sent. This is a considerable overhead, so care must be taken to perform pixel operations in batch. Obviously, an algorithm that generates random pixels on the screen would have very low performance.

One other hit to potential performance is the lack of double buffering. The LCD chip only has enough RAM for one set of graphics memory, which means active drawing occurs on the viewing surface. In modern day graphics pipelines, double buffering and even *triple* buffering are common place as they eliminate tearing and free the developer from having to clear the screen. On modern day graphics cards, clearing the screen is an extremely cheap operation – on the ILI9341, it's just as expensive as every other drawing operation.

5.4.3 Touchscreen Driver

The touchscreen will need code dedicated to polling the X+, X-, Y+, and Y- pins of the LCD. These will give voltage readings that can be used to calculate the position of a single touch. They can be read by using the built-in ATMega ADC. Due to their not being a dedicated touch controller, interrupts cannot be used to sense sharp changes. This will add to the processing time of the microcontroller's main loop as it will constantly have to perform ADC operations and comparisons.

5.4.4 Graphics Driver

Unlike the previous ILI9341 driver, our graphics driver will be in charge of taking the low-level primitives exported by the LCD driver and using them to draw useful screen elements. These include text, lines, rectangles, circles, and images. The driver will essentially contain a set of routines for drawing these objects given a set of parameters such as length/width for rectangles, radius and position for circles, and bitmap lookup-tables for the text. These functions and more are already created by Adafruit, but for the experience and control of designing the graphics routines, we choose to implement our own.

Due to the unique hardware and software constraints (i.e limited clock speed and memory), we must take care to not exceed the capabilities of the hardware. This means floating point operations, which may be required for shapes such as a circle must be optimized or not used at all. A quick optimization for floating point operations would be to use a $sin()$ lookup table and only integer multiplications. These performance issues will be addressed as needed and only if necessary. By avoiding unnecessary optimizations, we will save valuable time for building out the library.

5.4.4.1 Algorithms Necessary The functionality of graphics driver depends on some core algorithms for efficiently creating meaningful screen objects. One of these core algorithms is Bresenham's line algorithm. This algorithm needs to be efficiently implemented as it will be the base for nearly every derived graphics operation. For example, a transparent rectangle has four sides which results in four calls to this line drawing function.

5.4.4.2 Character Lookup Table In order to convey useful information, we will need to display text to the user. This text will be stored in an efficient lookup table for quick drawing operations similar to Figure 6. On a limited embedded system like this, there is a limited amount of time that can be dedicated for font rendering. To save on time, we will use an existing font available online. Adafruit also bundles a font in with their graphics library that is implemented as a function instead of a block of memory.

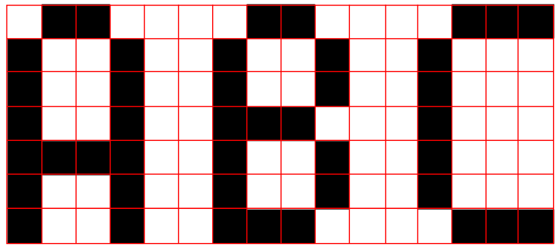

Figure 6: a raster image showing a possible character lookup table

5.4.5 UI Library

5.5 Android Application

For most WHCS users the mobile application will be the only physical interaction they have with the application. When we set out for development we wanted to make an easy to use application that would attract users to stick with our system. Operability and usability were emphasized in our design process. We wanted an appealing U.I. without complexity, after all we are targeting a simple solution to home automation.

5.5.1 Development Environment

Android is the mobile operating system that we chose to utilize for our BlueTooth enabled phone. The Android operating system is accessed through the Java language, which is a staple in the UCF curriculum therefore everyone in our group is versed in it. Developing on Android is also a free endeavour where as developing on an iPhone requires enrolling in the Apple Developer Program. These programs actually cost a good amount of money that is unnecessary to spend. The Windows Phone platform is another option for the BlueTooth enabled phone, but they are very unpopular so we chose not to target this platform. With our target narrowed down to the Android operating system, we had to research what the best environment for developing our application would be. There were three options that we considered for managing the Android project each with their own perks: command line tools, Eclipse, and Android Studio.

The first development environment we considered for our Android project was creating our own project structure and using command line build tools. There are also debug tools available on the command line for Android projects. These tools would be necessary in order to do our testing on Android Virtual Machines running on our computers. This approach favors people who are command line or terminal oriented. Linux is popular within our group and the ability to do things from the terminal is appealing so this approach seemed like a good one. We realized that with the design we had in mind for our project, it would become quite large and it might be difficult to handle without a dedicated IDE (Interactive Development Environment). This led us to looking into using Eclipse for developing our Android application. Eclipse seemed like a natural choice because it is what is recommended for using in the Java oriented UCF programming classes. The Android SDK provides an add-on for Eclipse that makes it a viable Android development environment. We were able to get this running and create sample Android applications. Inside of Eclipse the project structure for Android applications is laid out nicely. The debug tools are all organized at the top of the screen resulting in an easier development experience than debugging from the command line. The problem with using Eclipse as our IDE is that Eclipse is notorious for being slow and unwieldy.

Recently Google released a development environment named Android Studio that is made specifically for developing Android Applications. No one in our group had any prior experience using this IDE, however we realized that due to it being tailored specifically for Android it was probably better than anything else. This turned out to be correct, because it was much easier for us to create an Android project and navigate our code from within this IDE. We also decided to use Android Studio because it has built in Git support for source control. Figure 7 shows the important feature offered by Android Studio that we use for collaboration. This meant that as we were writing our code we could easily submit our changes to a remote Git repository.

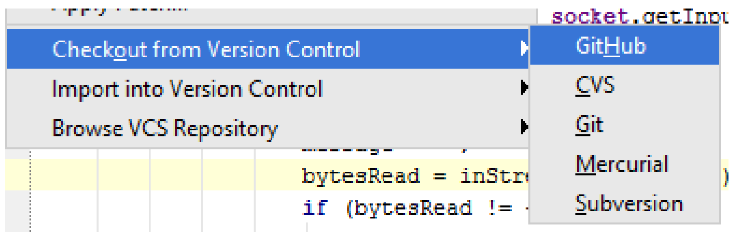

Figure 7: Git source control in Android Studio

5.5.2 Use Case Diagram

The central use cases for WHCS are toggling the state of certain devices within the home and monitoring certain states. For example a user of WHCS will spend most of the time turning on lights, checking whether a light is on, or checking the temperature reading of a certain sensor. There are certain other use cases that are necessary in order for WHCS to be a functioning application, as well as to make it have a robust feel. Features like speech activation and creating endpoint groups are usability features that are not necessary in order to accomplish the central goals of WHCS. Connecting to the base station the first time you use the application is a necessary use case that must be incorporated into the application. Figure 8 shows the use case diagram for the WHCS application.

The design for the WHCS application involves making sure that performing the common use cases such as checking status and toggling endpoints are very fast. The user should be able to perform these tasks without having any knowledge of how the application works. Speech recognition will be a supporting feature so it does not need to be a central focus like the area that will visualize the control modules. When the user wants to perform speech activation it will involve pressing a button to prompt the speech recognizer, and then giving a command to the WHCS. In order to make the speech activation feature more promising, the user will have the ability to rename endpoints for activation. Creating endpoint groups will be a feature that is not used frequently but adds a lot of value to the application. Users will only have to create an endpoint group once for it to last in the application. Creating an endpoint group will be a simple task involving assigning a group number to endpoints. That number will be the endpoint group, then that endpoint groups state can be toggled.

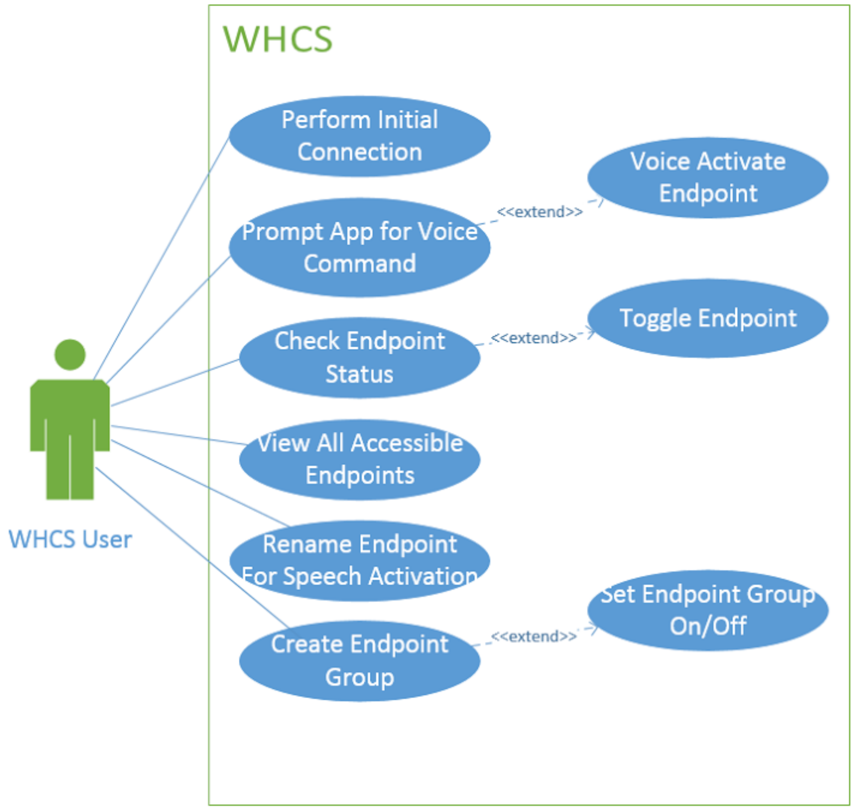

Figure 8: Android App Use-case diagram

5.5.3 Speech Recognition

The Android application for WHCS will offer speech activation capabilities. These will be on top of GUI activation capabilities. The speech activation sequence begins with the press of a button to start the speech recognition. The user will be prompted with a microphone and can then give his command. The commands will be formatted like "light one on." When the user gives commands using the speech method, a notification will be given indicating the success of interpreting the speech into a known command. If the user's speech does not match a known command, the speech will be shown back to the user to show what went wrong. We are predicting that the most frequent cause of this will be the Android phone mishearing the user. In the event that the speech matches a command, the application will display the command to the user and then perform it. The following flow chart in Figure 9 displays the sequence of events happening when a user performs speech activation.

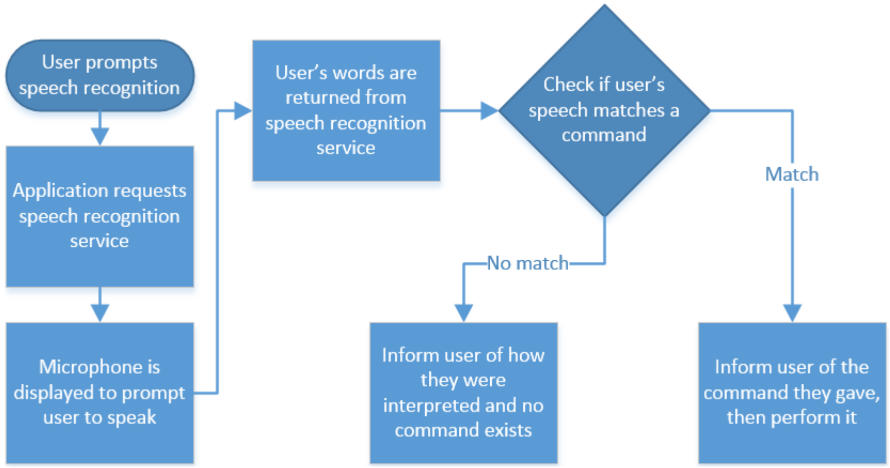

Figure 9: Android app speech activation chart

The goal of the speech activation feature is to be easy to use. In order to promote the usage of this feature we will add the ability for users to rename the endpoints that the speech commands will target. For example the user could change "light 1" into "living room light." This way the user could say "living room light on" to the application in order to turn on the living room light. To do this data structures will need to be stored in the application which hold the preferred name of each type of endpoint. Endpoints can be distinguished by the type they are, their individual identifier number and their preferred name. The preferred name should be stored when the application is closed so a permanent source of storage is needed to do this. The file system can be used or possibly a SQLite database.

In the code for our application we will be using the Android speech recognition API (Application Program Interface). Android has a speech recognition service that can be started by requesting it within an application. We will request this service to be run by using an Android construct called an intent, specifically the recognizer intent. Once the request the service to be run it gives us the text that it produced from listening to the user's speech. The code that performs this process ends up bloating up the application so we sought to develop a wrapper class in order to perform the request for the speech service and simply hand back the text. However because of the Android design philosophy, creating a wrapper class to start the speech recognition service was not easy enough to make it a worthwhile endeavour. Thus we concluded the best approach is to keep the calls to the Android speech recognition API within the class we use for our main activity.

5.5.4 BlueTooth Software Design

BlueTooth will be the technology that allows WHCS users to interact with the base station from the mobile phone. This means that proper functioning BlueTooth software must be written to ensure that users can interact with WHCS. From the user's standpoint the only knowledge of BlueTooth required will be the ability to perform an initial connection to the base station. Once a user has connected to the base station once through the WHCS app we will be able to cache the base station device and allow for automatic reconnection every time the application is launched. This is an important abstraction for the user because the user should not have to spend time handling BlueTooth connections every time they open the application. Figure 10 shows what the BlueTooth software will be doing whenever the user opens the Android application.

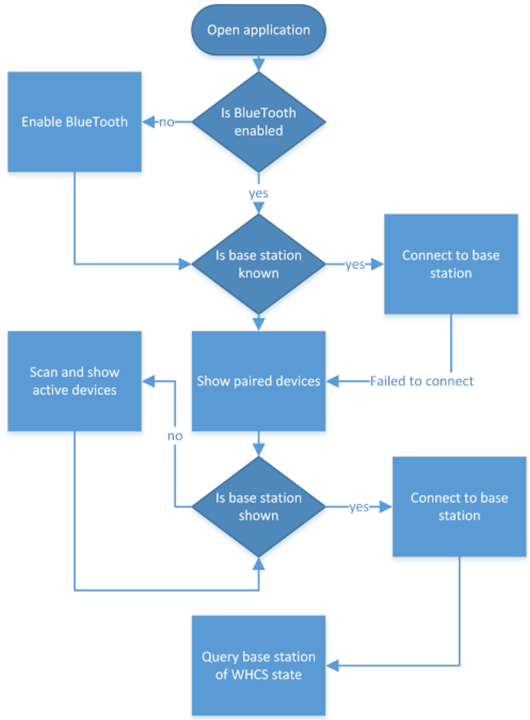

Figure 10: Android BlueTooth Startup Flowchart

In Figure 10 we see that the first check that is made is to ensure that BlueTooth is enabled. The Android operating system requires applications to ask the user whether they want to activate BlueTooth or not. It cannot just be turned on. If the WHCS application is opened and BlueTooth is off we will prompt to the user to turn it on and if they refuse we will exit the application. When it has confirmed that BlueTooth is on, the application can check to see if it knows the base station device. If the base station device is known then the application can skip asking the user what to connect to and can perform the connection automatically. This is what should be happening most of the time. If the base station is not stored in the applications data then the application will have to prompt the user to connect to a base station. When connecting to a device there are two possibilities for connection, paired devices and non-paired devices. The application will first show the user all devices that their phone has paired with previously, in case the application somehow forgot the base station. If the base station does not show up in the paired devices list, the user will be able to search for active BlueTooth devices and select the base station. At the end of this start up cycle the WHCS application will have an active BlueTooth connection with the base station that can be used for full duplex communication.

Our application will be leveraging the API and design guideline for using BlueTooth from Android phones. The underlying driver for BlueTooth communication utilizes sockets similar to network sockets in other languages. Android offers a class named BluetoothDevice which contains all the address information necessary for opening a socket. When our application scans for devices or asks the user to pick an option from the list of paired devices this will be to get the BluetoothDevice to open a socket from. Once we have obtained that BluetoothDevice we can create a BluetoothSocket through one of its methods. Once a BluetoothSocket has been opened through calling connect, an input and output stream become available that allow us to send and receive raw byte data. This is a primitive form of communication but it is also exactly what we want. All data that we send or receive from the base station over BlueTooth will be in the form of a byte array. This form of primitive data transmission allows us to implement certain communication protocols between the Android base station.

Once a BluetoothSocket has been opened on the Android device the application can begin communicating with the base station. We will use a communication protocol between the Android device to ensure the base station can properly interact with the application. This protocol will allow the Android application to give commands to the base station such as inquire about the state of the control modules or to toggle state within the system. Whenever the Android application wants to send a message to the base station the software will create a packet with a certain structure. The packet will contain a byte for letting the base station know that a command is being given, the command itself, any variables for the command, and then a byte for finishing the command. The base station will receive one byte at a time due to the serial nature of BlueTooth communication but it will be able to parse the packets it receives in order to figure out what action the application is trying to perform. Figure 11 shows a visual representation of the communication between the aplication and the base station.

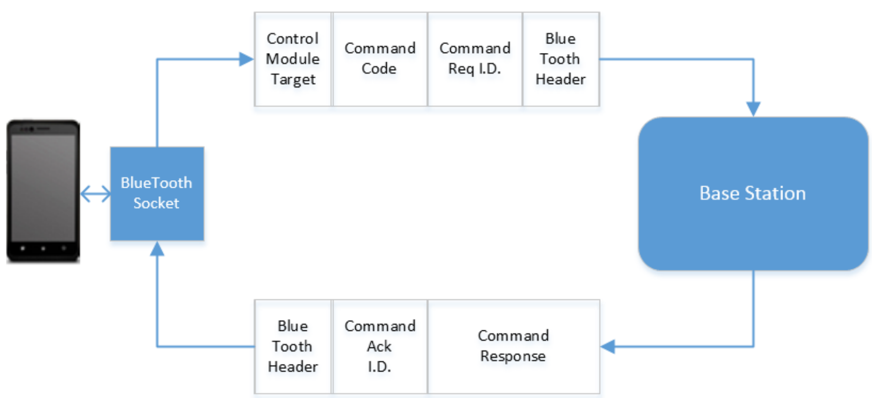

Figure 11: Visual of Communication Between Android Device and Base Station

5.5.5 GUI Philosophy

Our goal for the development of the user interface was to make something simple that users could navigate quickly and efficiently. There is no need for the UI to be deep or hold the user's attention. The only purpose of the GUI is to provide intuitive visuals for interacting with WHCS. When we developed the GUI we wanted to minimize the time it took for the user to open the application and make a change within the system. For example the user should be able to open the application and turn a light on or off in the shortest time possible. This means opening up to a screen that lists all possible end points in the system that can be targeted by a command. The top right layout in Figure 12 shows the view that would list all of the accessible control modules in the system.

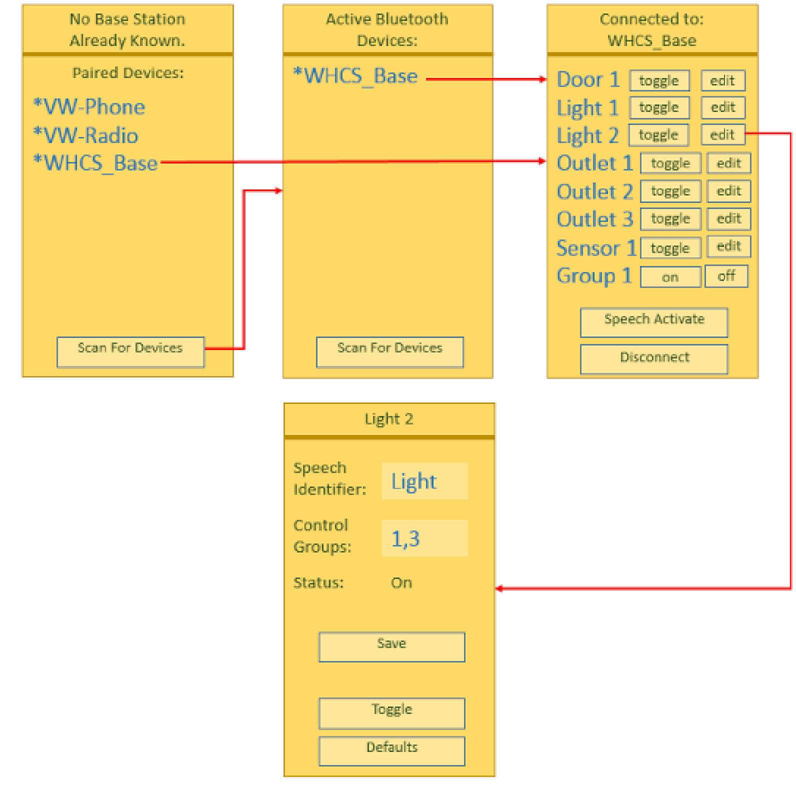

Figure 12: Android GUI Layout

As shown in Figure 12 there are layouts that provide support around the main list layout. The first two layouts in the upper left and upper middle are the what the user would see when the base station is not known to the application yet. The user would need to select the base station from a list of paired devices or perform a BlueTooth scan for active devices. Once the user has selected a base station then the base station can be saved in the application and the user should be able to avoid seeing these screens again. The user would be viewing the main list layout at this point. From the main list layout the user can navigate to the individual control module viewer. This will be achievable by clicking on the name of a control module or by clicking the edit button. The individual detail viewer will allow the user to toggle the state of the control module, change the speech recognition name of the control module, and assign the control module to a group. The detail viewer will also list the current state of the control module.

In Android different aspects of a GUI can be created in two different ways, fragments and activities. Typically fragments are used when two different screens serve very similar purposes or are trying to accomplish a shared goal. Fragments are typically used when exchanges are meant to be done very fast between screens. In the case of our application we will be using separate activities for each of the screens. This is a logical approach because the layouts in our application are independent of one another. The main list layout will serve as the root activity and any other screen will be an activity that is placed upon it. For example when the application opens up the first time it will try to open the list activity but will notice that it is not connected to the base station. This will cause the paired devices activity to stack on top of the list activity. When the base station is selected the paired devices activity can return the result of the selection to the list activity and the list activity can function normally. When the detail viewer activity is called it stacks on top of the list activity and when the user is done with it, it will be removed off of the stack.

To make our list activity look clean and function effectively we will create a custom adapter. In Android, adapters are the classes that allow objects to be transformed into data that a listview can turn into list items to be displayed to the user. The name of the adapter will be cmAdapter. The cmAdapter that we create will have an array of control modules as one of its fields, as well as a function named getRow that it inherits from its base class Adapter. The cmAdapter will know how to get the data from a control module object necessary to populate the main list. The main list activity will constantly call the getRow method that will be present in our adapter to fill the list. This creates a nice object oriented design for listing all of our control modules. If we want to display different data for control modules, we can simply alter the getRow method that is implemented in cmAdapter. Figure 13 shows the class diagram for the cmAdapter. The class is simple but provides important functionality for the Android application.

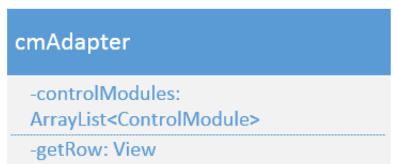

Figure 13: `cmAdapter` Class Diagram

5.5.6 BlueTooth Listener Class

When the WHCS application is communicating with the base station it is easy for the base station to be interrupted and start parsing communication using the UART interrupt vectors on the microcontroller. We want our application to possess the same event driven capability so we created the BlueToothListener class. This class handles listening for any incoming BlueTooth communication aimed at the phone. The class must be initialized by telling it what BlueTooth device it should be listening for. Once this happens it can create a thread and constantly check to see if the BluetoothSocket's input stream contains any data from the target device. If the inputstream contains data then we know that the target device has transmitted to the application. The BlueToothListener class raises an event whenever receipt of data has been confirmed. This allows the application to conform to event-driven Android philosophy. We can design around the BlueToothListener class and subscribe to the event it raises whenever data has been received. This is one of the core classes for communicating with the base station. Figure 14 shows the class diagram for the BlueToothListener class as well as the classes associated with it.

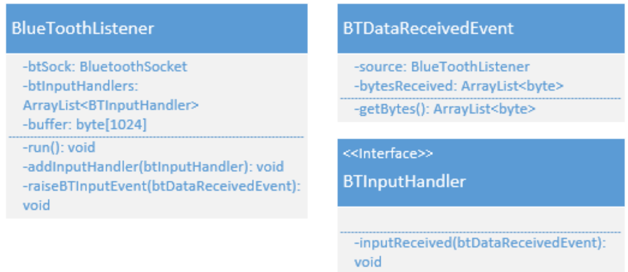

Figure 14: `BlueToothListener` Class Along With Supporting Data Structures

The BlueToothListener allows the application to directly hook up a parser for the incoming data. We can create a custom class that parses incoming byte arrays and transforms them into an understandable format for the application. This class would implement the interface for handling the data received event and could dictate what happens when certain data sequences are received. For example when the application asks the base station what control modules are currently known and active the base station would respond raising the data received event. The parser would begin working on the data received because it would have been subscribed to the event. The parser would realize that the data received is an indication of the state of the system and would have a case for handling what to do when this type of information is received. This would be how the communication protocol for receipt is implemented on the Android application.

5.6 Power Hardware

Throughout this section we will be discussing all that deals with the power. For reasons that will be discussed in greater detail in Section 5.6.7 we decided that each control module and the base station would have a power board that would be separate from the PCB of the control modules and base station. The reason for each power board is to convert 120VAC to DC lines of 3.3V 5V and 12V. We will also need to be able to switch on and off 120VAC for the outlet and light switching control modules as well switch on and off the 12V used to operate the strike.

5.6.1 Design Summary

The designs for each board will be mostly the same with slight variations depending on the application. This section will *not* go into the specifics of why certain designs were chosen over other designs but will provide a big picture view of how our design works.

To start off we will explain the black. Black is the color that is used to explain what is constant for every board design. Basically what the black line does is provide power to the microcontroller using AC outlet power. First the AC power is transformed with a transformer down from 120VAC to 24VAC this 24VAC is rectified using diodes into 33.6 VDC. At this point the line goes through a DC to DC converter that will transform the 33.6 V to 5V. This 5V line leaves the power board and enters the PCB containing the microcontroller and turns it on.

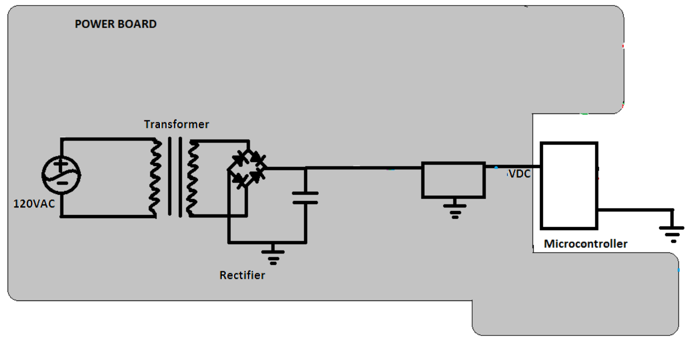

Figure 15: power board baseline design

The next line to discuss is the red line. The red line is used in both the light and outlet modules. The basic function of these control modules is to switch on and off power to either lights or outlets. Basically in addition to the line taken from the 120VAC to power the microcontroller we will have a line to power the actual application (the light and/or outlet). This extra line will run along our power board and will only be interrupted by a 5V operated relay. This relay will be connected to the microcontroller so that from the microcontroller WHCS will be able to open and close the 120VAC line. This is the easiest way to implement switching into our design. The only difference between the light and outlet modules is the load that is placed at the end of it.

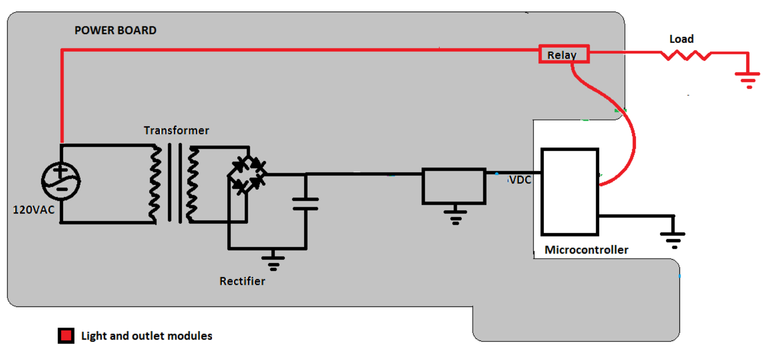

Figure 16: power board light and outlet control module design

The green line is very similar to the red line. The green line is used to explain the door access. Door access is fairly simple, it consists of providing or not providing power to the electronic strike in order to allow the user to lock and unlock the door. It too has a relay that is used in order to provide the switching. The only change is that electric strikes operate on 12V. In order to provide the 12V an additional DC to DC converter (in addition to the line used for the microcontroller) is used after the rectifier. The 12V line in combination with the relay from the microcontroller is all this module needs to perform its task of providing power to the door access module. It is however also equipped with a backup battery. The reason for this is that we still want the microcontroller to be powered even if there is a power failure from the 120VAC home power. The backup battery will not provide power to the 12V line meaning the strike will remain in locked mode. However having the microcontroller powered will allow it continue completing tasks such as checking the state of the system.

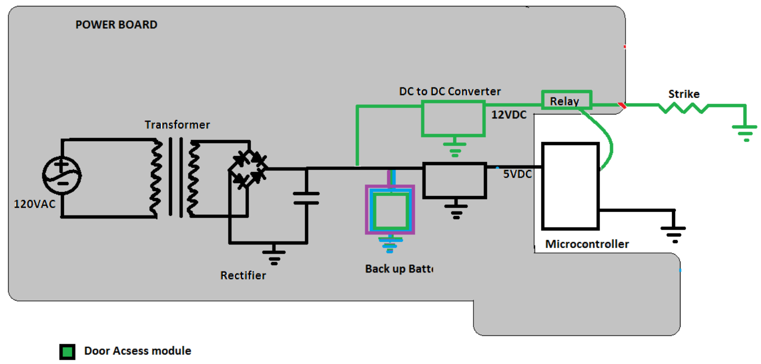

Figure 17: power board door access control module design

The purple line is the simplest of the modules. It is used to explain the module of the thermo sensors. this module really only needs the basic design of the black line that provides the microcontroller with 5V. Yet it too like the green and blue line is equipped with a back up battery. This way the information about the temperature of the home can still be gathered from the sensors even if there is a power failure.

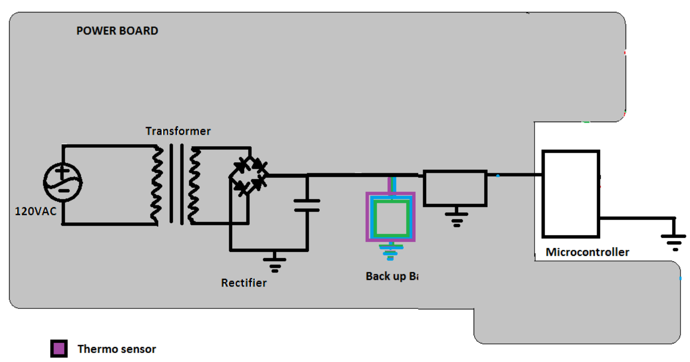

Figure 18: power board thermosensor control module design

Lastly and arguably the most important line is the blue line. This line is used for the base station. The base station in addition to the microcontroller will make use of NRF and Bluetooth which require 3.3V lines. The 3.3V line will stem out from the the 5V line as shown in Figure 19. In order to make this step down we will be using a linear rectifier. It too will be equipped with a backup battery in case of power failure. This will allow the base station to be fully operational even if the power goes out.

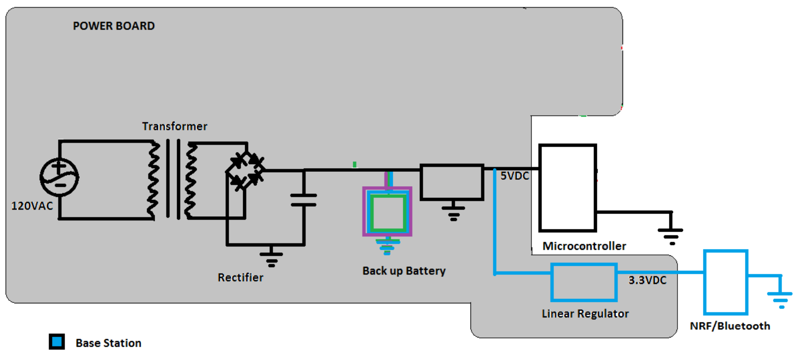

Figure 19: base station power board design

The only reason that red is not equipped with a backup battery is because a backup battery for red would serve no purpose. The backup batteries allow the microcontrollers of the control modules to remain operational, thus allowing the microcontrollers to complete small tasks such as checking the state of the system. For light and outlet applications however there is no need for this; it can be assumed that the state of the lights and outlets if off. There is no need to check this with a microcontroller and therefore a back up battery would be useless.

5.6.2 DC-to-DC Converters vs. Linear Voltage Regulators

In our control modules and base stations we are required to provide lines of three different voltages 12V, 5V and 3.3V. This can be accomplished with a voltage regulator or a DC to DC converter. Voltage regulators are variable resistors that dissipate energy as heat to get the desired voltage levels. The advantage of voltage regulators is that they are cheap. The issue is that they are highly inefficient. Linear voltage regulators are good for low power applications where not too much power will be wasted due to inefficiency. Whereas DC to DC converters are more appropriate for large step downs in voltage.

The basic tradeoff between the two technologies is cost vs efficiency. Dc to DC converters are capable of achieving efficiency levels as high as 95% but cost close to $10. The efficiency of linear voltage regulators depends on the difference between the input and the output voltage. Yet the cost of a linear voltage regulator is usually below $2. Power wasted in a linear voltage regulator can be determined by using Equation 1.

$$P_{wasted} = (V_i - V_o) * i_l \tag{1}$$

Where P_{wasted} is the power wasted, V_i is the input voltage, V_o the output voltage, and i_l the load current.

The basic question becomes how large of a stepdown are you expecting to have from your regulators. In our design (mostly because of the backup battery) we decided to have a step down from 34 volts down to 5V and/or 12V, as well as a step down from 5V down to 3.3V. Based on these step down values it makes most sense for us to use a DC to DC converter to step down 34V to 5V and/or 12V, and to use a linear voltage regulator in order to step down from 5V to 3.3 volts.

5.6.3 Backup Battery Configuration

Each control module along with the base station in WHCS will be equipped with a backup battery. In the case of power failure WHCS will still be able to carry out the basic function of checking the state of the system. Actual operation of some of the control modules will be impossible without the use of AC power. Yet checking statuses such as temperature and the position of door locks will still be fully operational. This is meant only to serve as a short term solution to power failure.

Here we will consider different designs to make a backup battery. We'll start with the circuit that was actually selected to be used in our design. The circuit below was made in Easy Circuit. The idea for the design came from the following link

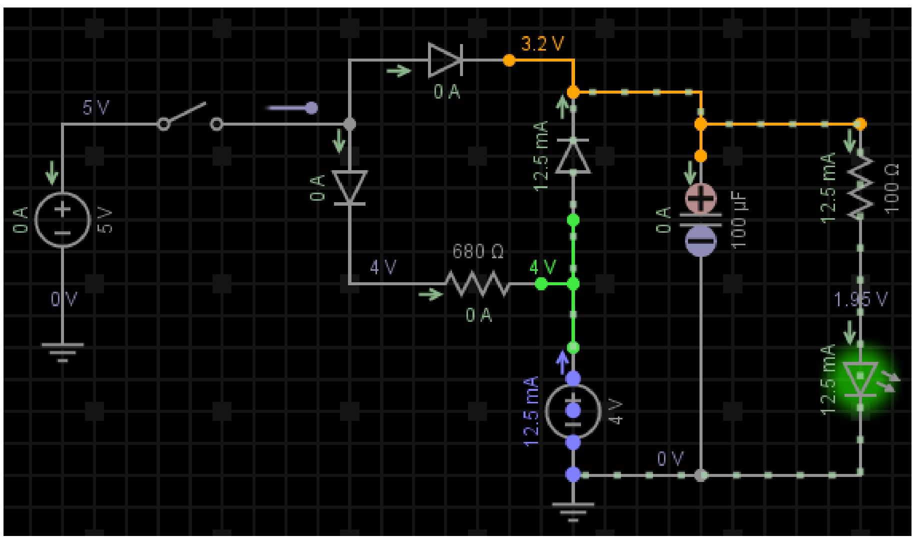

Figure 20: chosen backup-battery configuration[5]

This design is simple. The circuit being open indicates when there is a power failure, while a closed circuit signifies normal operation. The circuit shows two sources, one (the one farthest to the left) that is of a higher voltage and acts as the primary source and a secondary lower backup voltage source. Since the secondary source is of lower voltage it will not discharge until the voltage of the first source drops below a certain level. This is how tradeoff occurs. The secondary source has no potential until the first sources potential drops below a certain level. In Figure 20 we see that during normal operation (closed switch) that this design will recharge the batteries, that is if the batteries are rechargeable. This feature can easily be taken out by removing the diode and the resistor that feed into the secondary battery.

[5]Design idea taken from http://www.instructables.com/id/Simple-5v-battery-backup-circuit/. Circuit remade.

In this design it is very important that the secondary source be of a lower voltage than the primary source. If this is not the case the batteries will discharge even when the primary source is functioning properly. Initially we believed that this would be a handicap for our project and that a new design would have to be used. Yet we realized that there was a way to ensure that the primary voltage was higher than the secondary voltage. If we were to place the backup battery before the DC to DC converter, and allow the DC to DC converter to do a large portion of the voltage step down. Say we had the the transformer only transform down to 24VAC (roughly equivalent to 34 VDC) then had the DC to DC converter bring the voltage down to 5VDC. Our primary voltage would be 34V and our secondary backup source could be anything lower than 34V that is accepted by the DC to DC converter.

Designing in such a fashion has it's advantages and it's disadvantages. The benefit of placing this design right before the DC to DC converter is that no matter what the voltage is coming into the converter (as long as it is within the range or acceptable voltages for the converter) the output will always hold the same voltage level. The main disadvantage is that the required voltage rage needed by the voltage regulator may cause us to need higher voltage batteries than we would have needed otherwise. Say for example we need a 5V line, the DC to DC converter takes voltages from 9V-40V and converts it to 5V. For our back up battery we are now required to use a 9V battery whereas in another design we may have been able to get away with a 6V battery source.

Because of the high efficiency level of the DC to DC converters using a higher voltage battery than may have been required is not a problem of wasting power rather a problem of design cost. 9V batteries cost around $6 for a pack of two while AA batteries cost about $14 for a pack of 24. The cost difference a 9V battery and a 6V source with AA batteries is $0.33. The 9V battery is more expensive but it actually isn't that much more expensive. The cost/volt of a 9V battery is better than that of the AA batteries.

The design above works because we have decided to use a DC to DC converter with a decently sized voltage step down.If however this were not the case and the primary and secondary designs were much closer in voltage levels than an alternative design would have to be used. There are a few other design possibilities that were explored.

Another design that was explored was to use a relay in order to drive the switch. In Figure 21 current flows from the primary source to ground which activates the relay allowing the primary source to power the load. If there were a power failure in the primary source the relay would switch to circuit with the backup battery and thus the secondary source would take over. The main issue with this circuit is that it requires a line that goes directly to ground, thus wasting energy. The effect of this can be lessened by choosing a large resistor value. Yet in the end we decided to go with the first design because it provides the simplest solution.

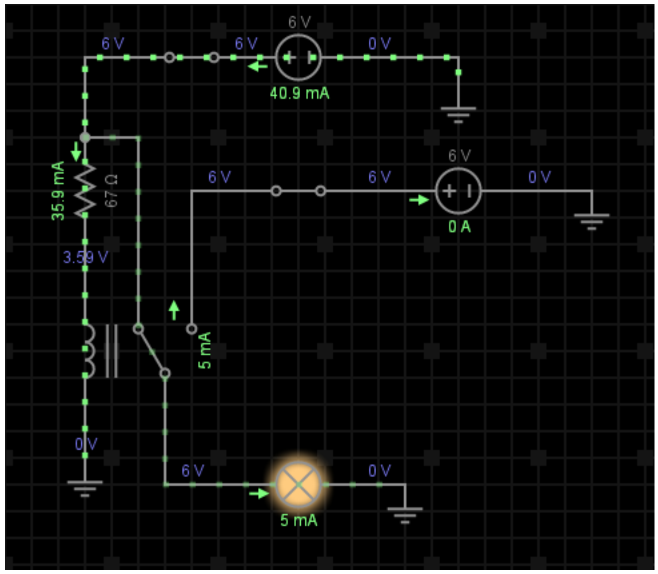

Figure 21: another backup battery configuration[6]

5.6.4 Transformer Choice

5.6.5 Power Consumption

5.6.6 Isolation

5.6.7 Power Through Hole Board

Sending in PCB's to be built can be expensive. Also the size of the boards have a large impact on the cost. Due to the fact that components found in power designs are large and will therefore be costly to place on a PCB we decided to self build a separate board for power. Not only is this an advantage because it is cheaper but it allows us keep high voltage AC isolated from the DC used for our control modules and the base station. Additionally each of our power boards are slightly different from one another so making our own boards will make it easy to customize each board for their specific needs.

After deciding that we needed a separate power board we had to decide how to build the board. The three candidates were: perf boards, vero boards, and etched PCB boards. Out of the three the team decided that an etched PCB would be the cleanest and would look more professional than an a perfboard or stripboard. Next we decided that a through hole board would be superior to a surface mounted board; mostly due to the fact that power boards can contain heavy components (for example transformers) and through hole boards are more mechanically sound than surface mounted boards.

In order to build our board we will be using Rogers RO4003. The primary reason we decided to use Rogers was because they provide free samples for learning purposes through

[6]This schematic was constructed using Easy Circuit, and the idea for the schematic came from a Stack-Exchange post.

their University Sample Orders Program. Since this is in fact a non commercial academic project we were able to order a sufficient amount of laminate material to complete our project. RO4003 is a double sided laminate typically used for high frequency applications. Building this board from scratch will give added experience to the members of the group, which is the ultimate goal of this project.

5.6.8 Schematic

5.7 Base Station

5.7.1 Software Flowchart

5.7.2 Control Module Data Structures

5.7.3 Networking State Machine

5.7.4 Associating With Base Station

5.7.5 Schematic Breakdown

5.8 Control Module

5.8.1 Software Flowchart

5.8.2 Schematic Breakdown

5.8.3 High-Voltage Control

5.8.4 Electronic Strike

For WHCS we knew that we wanted access control to be part of our design. Basically a way for the user to unlock and lock the doors from their smart device. We explored a number of different options for what kind of locking and unlocking mechanism we could use. First we considered servo motors. The advantage of using servo motors is that they allow for very precise control. The design would be fairly simple the rotating motor would slide a deadbolt that could lock and unlock the door. Figure 22 shows a simple graphic of how such a system would operate.

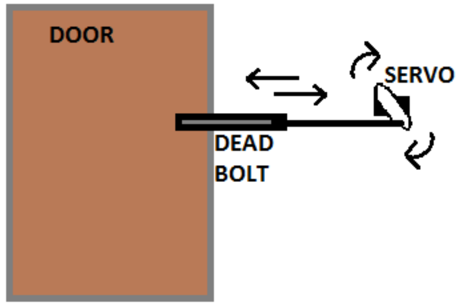

Figure 22: servo motor access control design

The fact that the servo motors allow us to control exactly how much rotate is an advantage for two reasons. One once the servo is done rotating we know exactly what position the lock is in, and two we know for sure that the lock will stay in that position. The other design consideration was using a solenoid to move a deadbolt lock. When activated the solenoid would push or pull the deadbolt into the locked or unlocked position. While this would work it's design is a little more complicated than the servo motors. Unfortunately the solenoid design would require some sort of locking mechanism once the deadbolt is fully extended. Plus it would be hard to measure whether or not the door really did get locked or not.

While both of these methods would have worked, in the end we decided that these designs were too mechanically involved and we wanted to focus our efforts on electrical and computer engineering designs. The alternative was to use a premanufacture electric strike. In the following sections we will discuss what design considerations were taken when selecting our strike.

5.8.4.1 Normally Open or Normally Closed The first thing we considered was whether we wanted a normally open lock or a normally closed lock. Normally opened means that the door requires power to be unlocked and is otherwise locked without power, while normally closed means that the door needs power in order to be locked and is only unlocked when the power is shut off. It was pretty easy for our group to decide that normally open was the better design choice because it would allow the door to be locked most of the time without wasting power. The only issue we saw initially was that it might be a potential safety hazard to have doors locked while there is a power failure. In the case of an emergency this could be a huge problem. We did however find an easy way to have a mechanical alternative (this will be discussed in the next Section 5.8.4.2) so that the safety hazard was no longer present.

5.8.4.2 Strike vs Deadbolt There are two main types of electric locks to choose from, electric strikes and deadbolts. While some may argue that deadbolts are more secure, electric strikes have the advantage that it they can be used with a regular door knob. This is an advantage because it allows us to include a door knob with a mechanical lock. That way if there is ever a power failure the mechanical lock can still be used. This gets rid of the safety hazard that could arise if for example a fire where to occur. It also allows for a backup system in case you were to lose your phone or if there were some sort of failure in the electronics that give the command to unlock the door. While perhaps there is a higher level of security that could result from using a deadbolt, the advantage that comes from using an electric strike outweighs the benefit or an electric deadbolt. Figure 23 shows the two methods for opening the door when an electric strike and a door knob with a lock is used.

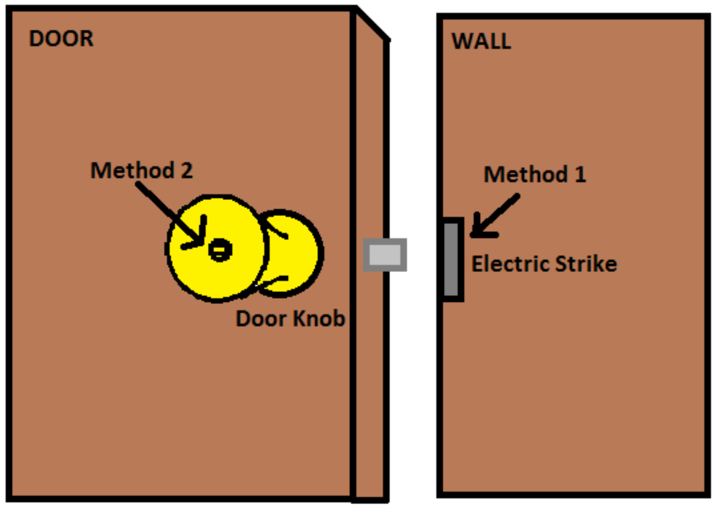

Figure 23: electric strike entry methods

5.8.5 Sensor Collection

5.8.6 Light Control

6 Printed Circuit Board

6.1 Software Considerations

Before designing any of our Printed Circuit Boards, we decided to analyze which software would allow us to do the job the quickest and easiest. Nearly all of the team was familiar with EAGLE as it's one of the most talked about board design software due to its EAGLE Lite version. Instead of going with the most common solution, we decided to compare EAGLE CAD to another open source solution: KiCad.

6.1.1 EAGLE

EAGLE PCB is commercial software for schematic capture and board layout. It supports a wide variety of features that would help us make our board. The only issue is that the normal software costs money. Luckily, they offer a free evaluation version that can only be used for non-commercial purposes.

This freeware version of EAGLE has strict limitations in the size of the board that can be designed and how many signal layers there may be. The size of any board is limited to 4 x 3.2 inches[7] and there may only be a top and bottom copper layer. These limitations would be a show stopper for a moderately complex board, but considering our project requirements, it would be suitable. If we are to consider future board designs for WHCS, we may want a more flexible solution.

6.1.2 KiCad

As an alternative to EAGLE PCB, KiCad performs admirably well. It has all of the primary features of EAGLE and yet, is completely free and open source. The benefit of this is that the whole suite of tools is cross platform, allowing group members to easily work together despite different operating systems.

One issue with KiCad is the lack of a built in Autorouter. KiCad provides an external router, FreeRouting[8], but it has experienced recent legal trouble due to one of the developers previous employers.

Another nifty feature that KiCad has is its 3D board view. Figure 24 shows the 3D view of an example board by Orlando Arias[9]. This feature is great for getting a sense of your board layout in relation to the selected footprints.

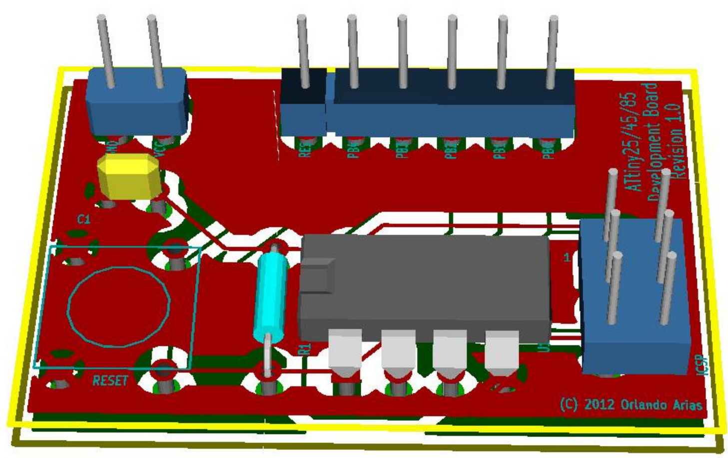

Figure 24: An ATtiny development board displayed in KiCad's 3D board view

[7] http://www.cadsoftusa.com/download-eagle/freeware/
[8] http://www.freerouting.net/
[9] A 3^{rd} year Computer Engineering student at UCF

6.2 Layout

6.2.1 Base Station

6.2.2 Control Modules

7 Prototyping

This section is in the process of being written.

7.1 Point-To-Point Transmission

7.2 Rogers Board Etching Prototyping

7.3 WHCS Proto-Panel

7.3.1 Materials

7.3.2 Dimensions

7.3.3 Sketch

8 Manufacturing

This section is in the process of being written.

8.1 PCB House

8.1.1 OSH Park

8.1.2 Seeed Studio

8.1.3 4PCB

8.2 Parts

8.2.1 Footprint (SMD vs Through-Hole)

In WHCS we had to consider two construction methods for our base station and control module boards; through hole boards, and surface mounted boards. Through hole board technology is the older of the two technologies and is currently much less popular than surface mounting. One of the of the advantages of surface mounting is that it takes up less space allowing more real estate for parts for a given board. Because surface mounting does not involve drilling it is simpler and faster to construct. Although there are some advantages in through hole boards for most applications surface mounted technology wins. Therefore in our design we will be using surface mounted technology.

8.3 Construction

8.3.1 Soldering

8.3.2 Reflow Oven

8.3.3 Proto-Panel

9 Testing

This section is in the process of being written.

9.1 Power Supply

9.1.1 5v Line Integrity

9.1.2 120v Line Integrity

9.1.3 3.3v Line Integrity

9.1.4 Battery Backup

9.2 Base Station

9.2.1 LCD Control

9.2.2 LCD and NRF Simultaneous

9.3 Control Module

9.3.1 Voltage Level Correct

9.3.2 UART chip debugging

9.3.3 Receive Commands

9.4 Door Access

This section is in the process of being written.

9.5 Android To Base Station Communication

9.5.1 BlueTerm

9.5.2 BlueToothListener

9.5.3 LED activation test

9.6 Base Station to Control Module Communication

9.6.1 LED Toggle

9.6.2 UART to Hyperterm

10 Demos

This section is in the process of being written.

10.1 Voice Controlled Light Activation

10.2 LCD Light Activation

10.3 Sensor Query

10.4 Fault Recovery (Loss of Power)

10.5 Remote Door Access

11 Project Management

This section is in the process of being written.

11.1 Budget

11.2 Parts Acquisition

11.3 Milestones

12 Appendix

This section is in the process of being written.

12.1 Appendix A - Figures

12.2 Appendix B - Tables

12.3 Appendix C - Complete Schematics

12.4 Appendix D - Copyright Notices