The Cool Roommate

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***Abstract* — The objective of the project is to responsibly increase home energy efficiency, while simultaneously providing a simple enjoyable experience for any user. The Cool Roommate provides an accurate third party, A.I. System, capable of controlling temperature environments using household infrastructure at an affordable cost. The Senior Design team decided to focus on energy efficiency and automation because we wanted to explore affordable modern day solutions to home energy conservation.**

***Index Terms* — Context Awareness, Decision Support Systems, Energy Efficiency**

I. INTRODUCTION

The environmental costs of energy are high and getting higher, with 65% of global warming pollution estimated to come from energy generation and use there is a call to be more responsible with our energy use. The cost paid by consumers is estimated to be as much as $25 Billion that is lost due to inefficient energy practices [1]. The Cool Roommate will be capable of reducing the energy deficiency found in common home practices by regulating household infrastructure such as the air conditioning unit, ceiling fans, air vents, window shades.

Heating and cooling together comprise about 42% of consumer home energy expenditures, on average, although much of this energy expenditure seems to be used for space conditioning during times that the home is unoccupied or occupants are sleeping [2]. Therefore, these "unoccupied" periods represent an often-untapped opportunity for the Cool Roommate to reduce home energy consumption. The United States Environmental Protection Agency, or EPA, has found that among households using thermostats for heating, it is estimated that about half of all households (49%) usually do not have someone home during the day. However, during the winter, less than half (42%) of households report turning the heat down and only 2% completely turn the heat off. A slightly higher percentage of households reported turning the heat down (46%) or off (6%) during sleep hours. The question remains as to why such a large proportion of households do not appear to be adjusting their thermostats according to occupancy [2].

The Cool Roommate looks to correct these setbacks and statistics with its automation abilities. Some of the key features of our design will take place in the success of reducing energy waste; the system will be able to:

- Evaluate current temperature conditions: The system will actively monitor temperature conditions and response will be based on user input.
- Specifying "target" zones: A user can use the application to designate which room the cooling system should focus on.
- Controlling the thermostat: A user will be able to specify what temperature they would like their home to be cooled to.

With multiple temperature sensors throughout the environment, the cooling vents can be controlled to open and close for maximum efficiency of airflow and distribution. Each room in the house will contain a configurable climate control. The Senior Design team has received funding from Leidos and pending funding from Duke Energy for a total of $1100. This covers the cost of buying materials to build the prototype for testing.

II. THE COOL ROOMMATE PROFILE

A. Overall System Design

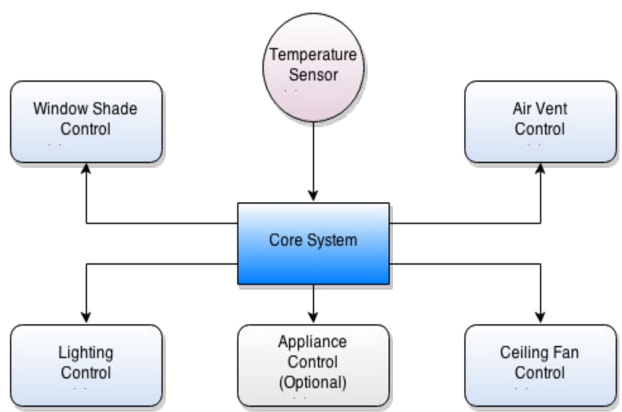

Figure 1. System Overview

The Cool Roommate has a simple system architecture that involves a master and slave communication line. The Master controller will be operated by the Tiva C launch pad as the Slave controllers will operate using a MSP430 microcontroller. Each Slave device will operate with at least one temperature sensor. Each function is independent and controlled by the Master. The Master also takes feedback from the sensor and sends different signals to each control according to the reading.

The Master and Slave will communicate wirelessly using ISM Bands at 868/915 MHz. The solution provides the system to operate at a much lower power transceiver. For the scope of the project, the system won't have access to the internet and will communicate directly with the controllers. For future scope and capabilities, the system should be able to access and communicate amongst the internet.

B. HVAC Control

A series of relays will allow control of a central air conditioning unit. This will be the safest option in controlling a large high powered appliance such as an air conditioner. The relay setup will allow control of the fan and also the compressor to ensure maximum thermal and energy efficiency. The HVAC control is responsible for the temperature and the strength of the air flow. The senior design team will not be responsible for building an HVAC system, but will have access to its control to accomplish the goals of the Cool Roommate.

C. Temperature

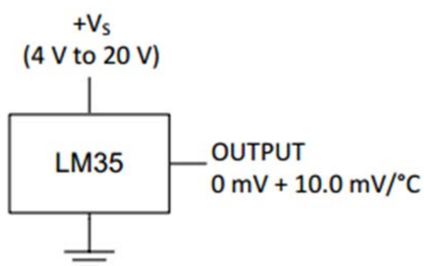

Fig 2. LM35 temperature sensor

Each slave controller will have an onboard temperature sensor. The temperature sensor will measure the relative ambient temperature of its location and relay it back to the room's main controller to be processed. The temperature will be able to change based on action from the HVAC control and system based on recordings from the temperature setting. When the temperature is too high/low the HVAC system will turn on and begin cooling/heating the environment. With the assistance and directed control from the Master controller, the ceiling fans and windows may be accessible to change the temperature. The temperature sensors are important as they act as one of the primary triggers for the Cool Roommate to monitor. The temperature sensor selected are factory calibrated with a typical accuracy of ±1⁄4˚C. A great advantage of the LM35 is that the temperature output is calibrated in the Centigrade scale while many other temperature sensors use the Kelvin scale.

D. Requirements for Temperature Sensor

Sensor requirements are derived from capabilities achievable within the scope and design of the senior design course. Relevant technologies were examined and considered when creating the sensor requirements. To determine what is most feasible for the system design these requirements have been decided to be what is most effective for the overall purpose of the system.

- The system's temperature sensors will provide a minimum effective range of -10°F - 110°F.
- The window shades will automatically close above 85°F.
- The user can specify a personal setting for the control over the window shades.
- The main temperature sensor will be located by the Master controller.
- The sensors need to be within 5% accuracy of true value.
- The system must be made available for future enhancement.

E. Fan Control

Components such as relays will make up the fan control module. Relays will allow the ceiling device be electrically isolated and encapsulates an immense amount of functionality. The fan will help circulate the temperature of the environment, The use of ceiling fans helps circulate cool air through warm spots of the room.

F. Vent Control

A metal gear servo will control the air conditioner vent. The metal gear servo will be able to provide sufficient torque required to open and close the ceiling vents. Air conditioner vents are typically made of metal which therefore may not be the easiest to operate. Plastic servo motors may have their gears stripped when attempting to turn the damper of the vent because the torque is too great.

In an effort to avoid a difficulty with the mechanics of operating a vent remotely, the team discovered a third party item named "Vent Miser". The Vent Miser is a vent that has operational mechanics that make controlling the damper more smoothly. In order to use the Vent Miser, a 3D printed key was design in autocad, and then printed to fit both the head of the metal servo and the key hole for the damper.

G. Window Shade Control

The blinds will operate similar to the vent control. A 3D printed key was designed and connected to the turn table on top of the blinds. As the metal gear servo rotates, the blinds will open and close. The servo is programmed to rotate 90 degrees each way in order to rotate the window shade.

H. Master Controller

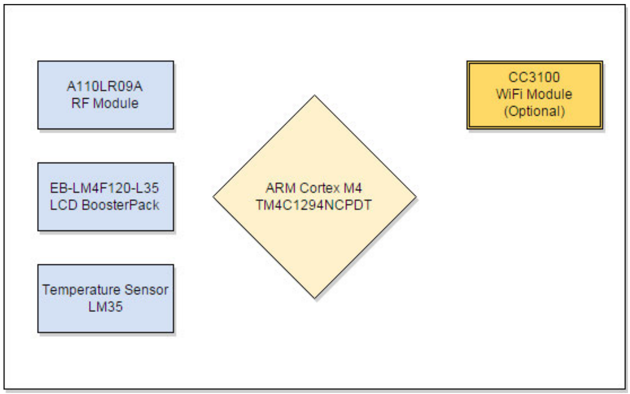

Fig. 3 Master Controller Overview

Texas Instruments Tiva C is a microcontroller that provides communication real-time communication control between Master and Slave components. The choice microcontroller offers a 32-bit ARM CPU with an on-board in-circuit debug interface allowing for more flexible programming.

The microcontroller has a variety of rich communication features that allow for connectivity between real-time control between performance and power. The integrated communication will provide its foundation for targeted rooms and functions. The microcontroller will provide sufficient computational power to execute the necessary commands to the slave controllers.

The Tiva C Series MCUs have extended memory durability by an order of magnitude beyond the competition. The minimum number of times the flash memory on these MCUs can be erased and reprogrammed is over 100,000 cycles. For most applications, this breakthrough eliminates any concern of wearing out the memory from re-flashing for data collection, configuration parameters or program modifications. The disadvantage to using the Tiva C as a microcontroller is the limited community support, as much is only from the manufacturer with technical documents and reference.

I. Slave Controller

Texas Instruments MSP430 is an ultra-low power microcontroller selected for various applications. The architecture, combined with low power modes, optimizes its remote applications considered for battery life. The digitally controlled oscillator allows wake-up from low-power modes to active mode in less than 1 microsecond. MSP430 MCUs also feature a direct memory access controller, enabling memory transfer with no CPU intervention. This means higher throughput of peripheral data and lower system power. The MSP430 MCU clock system has the ability to enable and disable various clocks and oscillators which allow the device to enter several low-power modes. The flexible clocking system optimizes overall current consumption by only enabling the required clocks when appropriate. This means that MSP430 MCUs can operate for decades on a single coin cell battery.

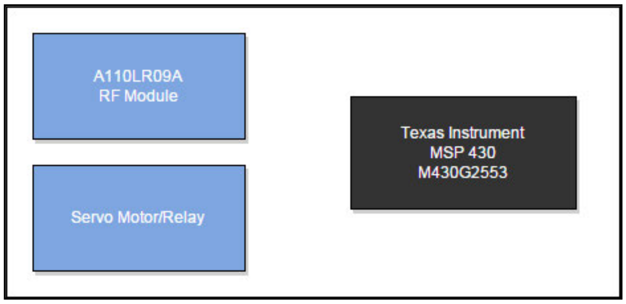

Fig. 4 Slave Controller Overview

J. LCD Touch Screen

Fig. 5 Master controller with the Cool Roommate logo

This EB-LM4F120-L35 is a LCD boosterpack for the Tiva C series LaunchPad. The EB-LM4F120-L35 is a 3.5 inch LCD module with a built in LED backlight driver circuit. The LCD connector is also able to be interfaced with a larger size LCD module. The resolution is 320x240 and has an 8-bit parallel interface. The touch screen opertates with a thin film transitor and is excellent for the simplistic design of The Cool Roommate because it allows for Plug-N-Play capabilites. This creates room for expansion of the system and easy maintenencing should a LCD fail.

K. Energy Consumption

Tiva C Series devices provide sleep, deep-sleep and hibernate (HIB) modes to save power when minimal functionality is required. In the hibernate mode, power to the entire chip is cut off except to the HIB block, leaving the MCU in a state where it can be brought back to life when the need arises.

III. SOFTWARE

The user interface for Cool Roommate is programmed with the concept to maintain a simple user interface to improve the overall experience. It is based on GRLIB from TivaWare and LCD_Screen Library Suite. Every single button is iconized, and any other value indication will be also shown graphically when possible. The master controller will have extra features in the UI, but every Cool Roommate device will have identical UI to keep the devices organized. The software of The Cool Roommate is programmed in Energia.

Energia is an open source IDE for electronic prototyping that brings the Wiring and Arduino framework to the Texas Instruments MSP430 based Launchpad. A great benefit to Energia is its cross platform abilities. Energia uses an mspgcc compiler because it focuses on the Texas Instruments MSP430 series Launchpads, different from Arduino which focus on Atmel based Arduino products. Energia also supports select Boosterpacks for the Launchpads allowing upper level expansion. Projects in Energia are referred to as sketch, and code is written in C or C++. Energia program can also run cyclically with the two basic functions, setup() and loop(). Energia comes with many example codes for different hardware to encourage a framework design. However since Energia is a newer platform, there is not enough libraries for some of the Texas Instruments' products. The community for support is limited; therefore its limited support is one of the disadvantages of it. However, coding in Energia is much easier than coding in Code Composer Studio. Shorter code and functions made the development of the software much easier than anticipated. Energia provides detailed documentation that explains the description and usage for the libraries on its website. When compiling the Energia program, it initializes the hardware according to the device that the developer picked; therefore, no extra configuration is needed. Energia contains a Serial Monitor for serial communication between the device and computer, this convenience feature makes additional terminal clients optional.

A. System

The system software for Cool Roommate is unique and organized. It implemented a simple scheduler method to have background processes run automatically so user experiences are not be affected by the waiting time. Inside of the Cool Roommate software, user will find the easy and efficient control. With all commands iconized, the device is easy to understand and eliminates the need for physical buttons.

Each Master controller device will have a color LCD with it to display all the information for the room that the user needs. User could adjust from the LCD to set or preset their own profile for the room. With help from the scheduler method, everything is possible.

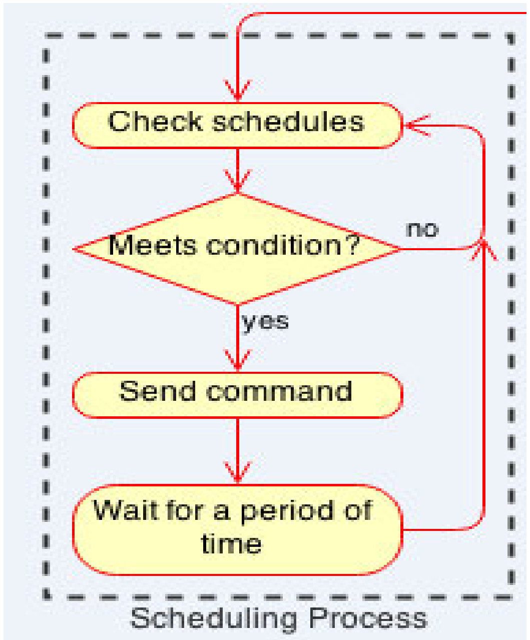

Fig. 6 Scheduler Flowchart

The Cool Roommate's software is also integrated with HVAC control. A simple but useful functionality that is required for every household. With digital reading from the temperature sensor, accuracy of readings from the sensor helps the Cool Roommate make the right decision. Because of the convenience of Cool Roommate, it needs to be included.

Since there will be multiple controller devices, source codes are generic in this case. It is easy to implement for new devices. Debugging, maintaining and integration could be done in one side, and it is suitable for the rest.

In addition, according to the hardware design and the software design, the system software is flexible for any other application, and there are a lot of spaces for improvement.

B. Language

The system software for Cool Roommate is coded in C, C++. From this aspect, there is not any harm to use high level programming languages to prototype and product implementation. Source code's compatibility, easiness and generic features are really good for transplanting the software to the other hardware. The diversity provides a lot of choices for developers to rapid prototype and integration.

For long-term consideration, the better the programming language, it becomes easier to maintain the product after it is published. The speed for new functionality integration will be greatly decreased; and therefore, labor and cost will be significantly conserved.

C. Debug

All software testing will be performed in normal room temperature within a climate-controlled environment to simulate conditions within a typical home. To ensure connectivity, basic deliverables will be sent between Master and Slave controller. Battery power will be measured to ensure devices are turned on. Visual inspection conjunction will be performed on circuit boards and motors to ensure no blockage, or shortage of devices prior to software testing.

IV. WIRELESS CONNECTIVITY

In the communication network of Cool Roommate, there are two different types of communications. The first is the communication between the slave controller and its children controllers, which are the window shade control, fan control, and air vent control. The second type of communication is the communication between the master controller and slave controllers. Each slave communicates to the master and the master reciprocates to slaves. However, for security reason, each slave will be isolated. Therefore, a slave cannot talk to other slaves within the network.

The system will operate within the US 868/915 MHz ISM bands governed by the Federal Communications Commission (FCC) regulation on low-power, non-licensed transmitters within the U.S. The rules for these regulation are documented in Part 15 of Title 47 of the Code of Federal Regulations ("FCC Part 15"), which is subject to two conditions. The first condition is that the device itself may not cause any harmful interference, and the second one is that the device must accept any interference received, including those interference that might cause unexpected operation.

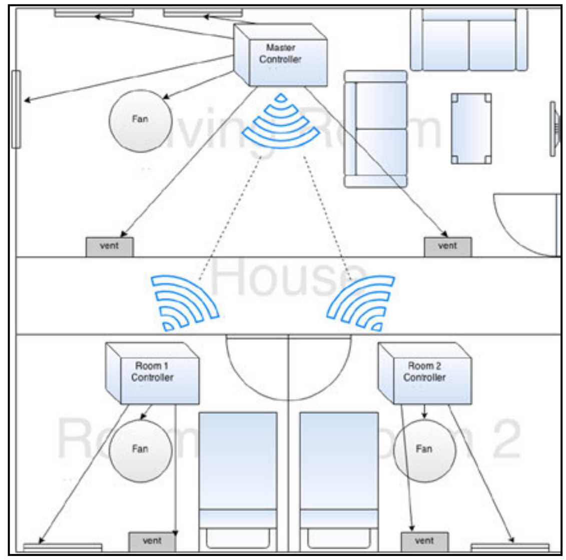

Fig. 7 Connectivity Demostration

A. Requirements for Communication

The Communication requirements are derived from capabilities achievable within the scope and design of the senior design course. Relevant technologies were examined and considered when creating the communication requirements. In order to have the proper communication between wireless components these requirements have been decided.

- Short range wireless communication less than 50ft.
- Master Controller will be able to communicate with a minimum of 2 slave controllers at once.
- Slave Controller should be able to communicate data and receive commands from master controller simultaneously.
- Wireless communication should be capable of passing through walls consisting of ply wood and/or dry wall.
- Wireless communication should be capable of passing through an aggregate wall width of .3 meters.

The Cool Roommate is depending on a wireless communication between the master and the slaves, and between the slaves to the minor controls; therefore, latency should need to be as minimum as possible to be able to synchronize every single piece of information. The expecting delays between the communications should be between two to three milliseconds.

V. Prototyping and Testing

During the prototyping and testing phase all hardware were tested in normal room temperature conditions within a climate-controlled environment to simulate conditions within a typical home. To ensure that each trace is providing an optimal connection, numerous continuity tests utilizing a digital multi-meter were performed. Each pin was checked to make sure that it is going to its corresponding destination and confirm the copper trace on the PCB. Visual inspection in conjunction with voltage readings were performed to accurately ensure that each integrated circuit was functioning as expected within its limits.

A. Relay Testing

The relay circuitry was manually triggered via the slave microcontroller. When given a signal to trigger the relay, the relay should have completed the corresponding circuit and allow current to pass through. The test would have verified against unintentional relay switching and adequately ensure a solid connection is made when triggered.

B. Temperature Sensor

Ambient air temperature measured with a temperature sensor was checked to ensure accuracy by cross-referencing with multiple other thermal sensors. Some examples are an infrared temperature gun and thermostat.

C. LCD Module

To ensure accurate color representation and touch screen accuracy, a calibration was performed then a short testing program was run. The test program allowed the test operator to verify touch location in the module registers to safeguard against manufacture defects. The program had also included multiple reference images to verify black level, white level, sharpness, color saturation, and color tint.

D. Wireless Module

Wireless communication was verified by manually sending data from the master controller to each slave. The test will verify that each controller is able to send and receive the correct data accurately with minimal losses. A short script was used to send and receive data to each unit one at a time at varying intervals. Then transmit and receive multiple packets simultaneously to simulate the system at max capacity.

E. Motor Control

The window blinds will be manually operated to preserve its structural integrity and calibrate speed and movement accuracy. Accurate timing and precision were measured to confirm that the motor is moving as expected and reduce unexpected complications. Air conditioner ventilation control were accurately assessed and calibrated. Signals were given to the motor control manually one at a time then movement between each position in every combination will be assessed.

F. Comprehensive Testing

After each component was assessed against defects, a comprehensive test program and procedure was run. The program improved debugging any problems that may occur within any feature.

G. Power Supply

The power supply on the slave controllers consist of two main components. The first is a 5 volt integrated switching regulator for the accessories such as temperature sensor, servo, and relay. The second component is the 3.3 volt linear regulator for the main microcontroller.

The main 5 volt integrated switching regulator is an LM2825-5.0. This component was chosen because it can provide power efficiency of up to 85% while producing an output of 1 amp. The main benefit of the integrated device is that it can accept a wide input range from 4-40 volts DC. The flexibility of input voltage allows the power supply to be integrated in a variety of applications such as wall warts, batteries, and more. In addition, we have included a bridge rectifier to allow an AC input from a 120 volt to 24 volt transformer.

The 3.3 volt linear regulator is being powered by the main 5 volt regulator. We chose to use a linear regulator because it can provide the most cost effective clean power source for the microcontroller.

In addition to both voltage regulators, there are capacitors in parallel with the 5 volt and 3.3 volt lines to filter out unwanted high frequencies. The capacitors also provide a short power storage in case of anomalies.

H. Battery

The Zippy Flightmax is being used as the battery for demonstration purposes because it allows proper power and durability to operate. The power source is a three cell lithium polymer battery that offers 2650 mAh. When designing the Cool Roommate size and aesthetic appeal were considered during this decision. The battery’s compact size, weight, and capacity are all capable and fulfill the requirements listed to function the project. We estimate that this battery can supply enough power to last months before a recharge is necessary. For a full product detail see Table 1 below [3].

TABLE 1
Summary of Battery

Capacity(mAh)	2650
Cell count	3
Parallel	1
Discharge (c)	20
Burst Discharge (c)	30
Weight (g)	212
Max Charge Rate (C)	2
Length-A(mm)	137
Height-B(mm)	45
Width-C(mm)	16
Voltage	11.1v
Balance Plug	JST-XH
Discharge Plug	XT60

I. PCB

The PCB for the slave controller contains a modular and customizable design. Every slave controller will have a wireless module, microcontroller, five volt switching regulator, three volt linear regulator, temperature sensor, and pin headers for ease of access and control. Each slave controller will have the optional ability to house a relay and bridge rectifier depending on its application and placement within the system. This allows us to minimize unnecessary wires and components to further maximize cost efficiency and reliability.

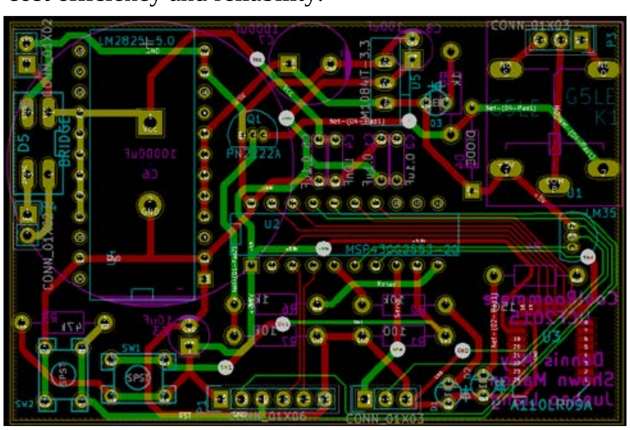

Fig. 8 Slave Controller PCB

All passive components such as resistors, capacitors, and diode are placed in a common location to reduce overall footprint and improve accessibility in assembly. The layout is designed to have components on both sides of the board to reduce manufacturing costs. Trace widths are typically either 10 mil or 32 mil to ensure that each connection has the least amount of resistance possible. To improve thermal resistance, a copper fill is placed throughout the board with a 10 mil minimum clearance from the traces. The overall size of the slave controller PCB is 5.69 square inches.

VI. Design Constraints and Difficulties

During the development of The Cool Roommate, the senior design team encountered several difficulties. Some foreseen constraints at the beginning of our project include hardware performance, power and torque issues, and time. Powering the servos that would rotate the vents and blinds were considered to be an issue as there was concern that there would not be enough force to rotate the axis enough from a low-power compact servo.

Time was a concern given the two semester limit to design, implement and integrate a system. The design team handled this restriction by organizing weekly face to face meetings and created weekly time tables and goals to accomplish in order to stay on track for deadline. There were no deadlines missed, however there were some unforeseen delays such as backorders on products needed to finish the system.

When considering power for our demonstration of capabilities we wanted a close to manufacturable product, while staying within the scope of the course and under budget. Initially the team was going to select a battery pack powered by over-the-counter batteries. However the teams' direction was to demonstrate a functioning system with a rechargeable battery with minimal self-discharge and memory effect. This allowed the Senior Design team to continue to be consistent with testing purposes and achieve consistent power across the platform.

The largest difficulty the Senior Design team faced was the PCB design of the Tiva C microcontroller. Initially, the team had difficulty creating a schematic to use for design. There was limited community support beyond data sheets from TI, and the group had limited knowledge and experience working with the microcontroller. When testing the board schematic, initially the team ran into several errors when attempting to write to memory. The software would not flash to memory when the microcontroller was off of its packaged Launchpad. A mentor was sought who was able to assist in the compiling error, but could not assist in the problem that followed when no output was produced after a successful program write to memory. Mentors and community support was sought again, before the Senior Design team decided to focus efforts on software and just use Texas Instruments Tiva-C series TM4C1294XL LaunchPad.

VII. Conclusion

The Cool Roommate was a two semester long project that provided to be a valuable learning experience for the members of the group. The members were able to strengthen their technical understanding about electrical engineering design as well as focus on the management skills that make successful projects come to life.

Across the development of The Cool Roommate, the contributing ideas from each member and mentor helped bring the system to life. The idea that simplicity is the best for design allowed us to expand our capacity and accomplish our overall goal. It took trial and error during the design stages to allow for a functioning PCB board, but with intuition and the team's intelligence we were able to create a great design that allows for future availability. There were many takeaways from the project, one would be the importance of having strong community support.

The team and mentors at the University of Central Florida's Innovation lab were tremendous in the help of 3D design and integration of parts. With strong support for debug and troubleshooting, along with test and integration the project was able to stay under budget and meet all goals and requirements.

Acknowledgement

The design team for the Cool Roommate would first like to thank our sponsors for believing in creating a more efficient home lifestyle. We would also like to say thanks to our mentors and the members of the innovation lab for providing us with help and continuing motivation to succeed. The group gratefully appreciates the review panel for taking the time to evaluate our project and we hope that the enthusiasm for a more efficient home life style is shared.

References

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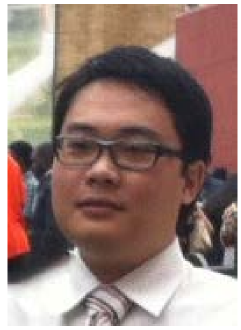

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Shawn M. Mahon is pursuing his bachelors in Electrical Engineering from the University of Central Florida. Mahon has worked for UCF and Lockheed Martin's College work experience for three years and has hopes to continue education for an MBA from Harvard Business School. Mahon is currently performing research on technological singularity under Dr. Kapoor. He is currently Vice President of Finance for Delta Upsilon Fraternity.

Dennis Moy is an Electrical Engineering student from the University of Central Florida. He has interned at Lockheed Martin during summer of 2014 and will be beginning his career at Lockheed Martin in King of Prussia, PA as a Systems Engineer. He is currently an active member in the Robotics Club at UCF designing and building a ground vehicle for the IGVC competition in Rochester, MI.