Automatic Aerobic Composting Machine

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1.0 Executive Summary

This document will discuss the design of an automatic aerated compost machine design complete with all of its core efforts. Some of these efforts include research, schematics, block diagrams, parts list, and test procedures. A user manual will also be included to share the details of setup, operation, and maintenance. Provided to the viewers are all of the necessary details outlining the prototype development plan so that a full understanding can be acquired. Additionally, provided are all instructions on the assembly and creation of the prototype for individuals or teams who wish to replicate the device. This is a comprehensive project that reflects the team’s combined knowledge and experience with sensors, mechanical systems, pumps, application software, microcontrollers, PCB design, and power systems. Not only does this project contain the expansive paths of development but it also provides a foundation on which to build upon. The prototype provides a base that can be expanded and help to make an impact in reducing the amount of waste that would have ended up in a landfill. Its ability to have uninterruptable power provided by a battery system that is charged by the sun enables the device to be used in a multitude of locations and for a variety of end users. Sensors are placed in three strategic locations, each with one moisture and one temperature sensor, to collect live information about the material being composted. Those sensors are powered by the power system and the measurements are fed back to an MCU that interprets that information and makes decisions on how to optimize the process. Based on that information, moisture content and temperature are monitored and controlled. Temperature is controlled with a fan and heater while moisture content is regulated with the use of the fan and water pump, depending on the need to increase or decrease the value most recently measured. While moisture and temperature is maintained, a motor is rotating the drum, and in turn the material, to ensure that all possible surface area is exposed to fresh oxygen and moisture if need be. Data is vital in optimizing the composting process and so to provide end users with this information included is wireless capability to forward all possible machine state information to a mobile application. This feature places the end user in a position to be in control of their composting process. Custom or automatic options are available for those who have varying levels of intended participation in the overall process. The hope is to develop a dependable control system that can be translated to multiple size mixing configurations. This system as a whole has made the most of an open ended, project focused course. The learning that has occurred allow us to select future projects that may have a different end use and application, but still contain an MCU, power system, sensors, motors, and pumps. Additionally, the control algorithms utilized are able to be applied to varying industry applications. The framework of features and capabilities was focused by the requirements of the Senior Design process. After deciding on the project and its features it is ensured that this final document, and all of its contents, meets or exceeds the expectations of Senior Design I. Through weekly meetings, the creation of a baseline Gantt chart to follow and update, maintained communication to overcome technical challenges and scheduling difficulties, the document reflects these qualities and equal team member participation. The accumulation of these efforts, along with hours of brainstorming, discovering, and writing, has allowed the achievement a comprehensive document on how to develop this capable prototype.

2.0 Project Description

This section serves to provide the motivation for developing an automatic composting machine as well as to portray the goals and objectives that such a machine should strive for. Since composting is not a very popular activity within the US, a review of the aerobic composting process is given in order to inform the reader about some specifics regarding compost and how it is made. Finally, this project's requirements and specifications will be presented to show how the automatic composting machine will meet the discussed goals and objectives.

2.1 Motivation

Almost everywhere, people are generating massive amounts of waste that ends up sitting in landfills. Over 7 billion people live on Earth and every single person produces an amount of waste in their lifetime. For example, other statistics say that the average American throws away 4.5 pounds of trash a day [25]. Since food is such a large part of people's lives, we lead the world in having harmful amounts of food wasted. "Roughly one third of the food produced in the world for human consumption every year — approximately 1.3 billion tonnes — gets lost or wasted" [25]. Economically, farmers and food companies in turn wastefully use chemicals, like fertilizers and pesticides on growing their large production farms on food that is eventually not used for anything, but thrown in garbage heaps and landfills. They also squander many other resources including fuel for transporting the large supplies of food everywhere around the world, water and land for irrigation and growth of the crops and land, and energy, labor and capital for the collective effort in harvesting and processing all the massive amounts of food. With such a high amount of food waste, a lot of damage is unfolding upon the planet. Not only is the world systematically being wasteful of resources, but humans are contributing to the effects of global warming. Due to the fuel used in production and rotting food, one of the most harmful greenhouse gasses is continuously being generated. Methane contributes to the hauntingly increasing climate changes that the Earth is experiencing from global warming. According to food loss studies from the UNEP, organic waste is the second highest component of landfills in the United States, which are some of the largest source of methane emissions. This raises the question, what can the human race do to slow down this deterioration of the planet?

Food and organic waste can be transmuted into a nutrient-rich soil that is capable of nourishing substantial plant growth. The compost material produced is valuable and can be sold, turning waste into something potentially profitable. While large, industrial-size composting already exists for processing food waste from larger facilities like restaurants, there are limited mechanisms for smaller individualized systems that can be used in homes or on farms. Much of the population does not give any regard for their trash and are not conscious of their carbon foot-print, but there is a growing public awareness on the issue of global warming. Many people do not individually compost for many reasons, like lack of awareness, time, and understanding of the biological composting process. Given a proper and easy-to-use interface, maybe the world can tackle its methane and waste expenditure issues, as well as profit from a resourceful product, simply with the development of a composting mechanism. This project plans to tackle the lack of efficiency in food waste management and contribute to the advancement in environmental recycling technologies that will hopefully impact the world in a positive direction.

2.2 Goals/Objectives

In designing this product, the main objective is to provide a system that will enable anyone that produces food waste to easily convert that waste into a mature and usable compost. Grid independence, automatic operation, optimization of the composting process, and simple device interactions all play a significant part in obtaining this ambitious goal.

The composting machine desires to be grid-independent so that not only will it be beneficial to the environment in finishing the loop of discarding organic waste but also in using renewable energy from the sun through a solar panel and rechargeable battery. This will allow the machine to be functional in practically any location outdoors where ample sunlight will be encountered. It also provides a way in which other countries that may not have the benefit of readily available power in their home to receive the machine and not have to consider how the device will be powered. Another goal to help enable anyone to use the composting machine will be its automatic feature for monitoring and determining the best way to produce mature compost. Since many people today do not understand the core aspects of composting and have never composted before, having a system where minimal user interaction is needed during the process will allow this device to be more successful and popular to a general audience. Considerations in today's market drive this project towards a system where the user will only have to input the correct materials (food waste, yard waste, and water), press a button for starting the process, and wait a specified amount of time before their compost is ready to be used. This inherently drives the design toward a goal of optimizing the composting process during automatic operation. Through the use of sensors, it is possible to interpret critical moments during the composting process which will then be used to help drive the design of special algorithms that decide when and how to act on the inputted organic waste to help produce a mature compost. Through this optimization in the control algorithms users will be able to have confidence that their compost will be produced correctly, efficiently, and with little monitoring and action required from them.

Although the composting machine will be designed with the simplest user in mind, steps will be taken to allow a pleasant experience for those that are more experienced in the composting process and would be considered experts in their community. The goal is to provide those users that want a simple approach to composting with an automatic solution with minimal interference while also allowing for more experienced composting users to manually control how the machine handles certain situations during the process. This would be accomplished through allowing certain criteria in temperature and humidity to be set by the user and adjusting frequencies for drum rotation, misting sequences, and other features. Giving this level of control to the user will enable them to make a more refined compost that may suit their needs better than that produced by the automatic operation of the machine. In order to deliver these controls and adjustment of settings, a goal is set to make the user interface simple and clean so that interaction with the composting machine is intuitive and seamless. Through a touchscreen display on the composting machine, a layout will be chosen that allows the user to understand intuitively how to set controls and see usage statistics such as power consumption, temperature ranges achieved, and humidity differences throughout the process. It is also desired that the user have access to all of this information through a mobile application that consists of a similar UI that is experienced on the device itself.

Allowing access to the automatic composting machine through a mobile application opens the door to another objective that will be to allow the user to access information about their compost from any location through internet connectivity, and be able to control their machine on the fly with modern features that come with smartphones today, such as voice control, alerts, and exceptional user interaction through well-designed applications. Having the composting machine join the many other devices that are connected to the Internet of Things will allow the user to take advantage of using their phone as the central hub, where they control those devices along with the automatic composting machine.

2.3 Aerobic composting process

Composting is a biological process where organic materials are decomposed into what is known as compost. Compost is not the same as fertilizer, as fertilizer is used as nutrients mainly for the plants, while compost is actually nutrients mainly for the soil. Fertilizer being focused mainly for the needs of the plants can often be detrimental to the soil as it hinders the growth of microbes living in the soil that are there to keep the soil healthy. Thus, the reason why compost is so important is because it stimulates the growth of these microbes and increases the health of the soil, as stated in [6]. Over time, the soil becomes nutrient-rich soil that is beneficial to both the plants and the vegetables.

At the most basic level, the process of composting merely requires the accumulation of damp, nitrogen and carbon-rich materials in a pile and waiting for the matters to decompose over the span of weeks or months. More advanced and modern methods of composting consist of multiple, closely monitored phases with measured levels of inputs such as temperature, moisture, air, as well as nitrogen and carbon-rich materials, which are simply referred to as green waste and brown waste, respectively. At a more in-depth level, composting consists of two main types: anaerobic and aerobic. As the names suggest, anaerobic composting is a type of compost process in which no oxygen is introduce to the pile, which will take much longer to produce compost. On the other hand, aerobic composting processes at a faster rate through the consumption of oxygen as it is required for the microbes to survive and break down the materials. Figure 1 shows the general process for aerobic composting, showing the different inputs and outputs of the process.

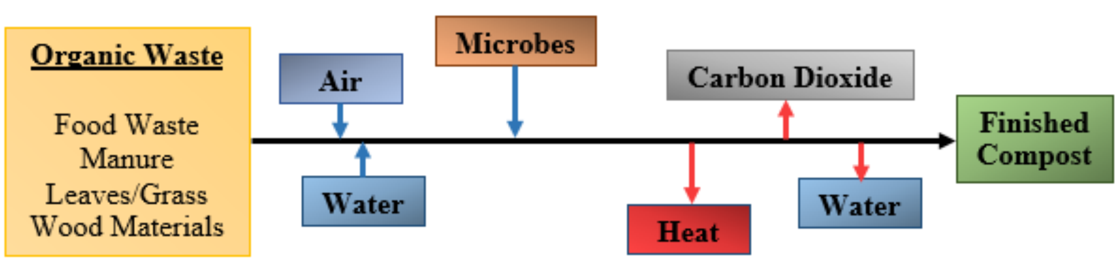

Figure 1: General Aerobic Composting Process

This project will focus specifically on hot composting combines with the use of a rotating container. This method consists of combining both brown waste and green waste together into a container, keeping track of the Carbon-Nitrogen (C:N) ratio. Too little nitrogen and the compost pile will not be able to generate enough heat to eliminate the pathogens that might be present inside the materials. However, too much nitrogen can cause the pile to become too hot, killing all microbes including the beneficial ones, or it can cause the pile to become anaerobic, producing foul-smelling odor. The standard recommended range for C:N ratio during the beginning of the composting process is around 30:1 according to [2]. In general, the content for carbon-rich materials should always be higher as this will prevent the pile from having an excess of nitrogen. Having too much carbon will slow down the composting process, but it will produce a sweeter smell as opposed to the rotten, ammonia smell from having too much nitrogen [4]. Table 1 shows a list of the common materials that are used in creating compost.

Compost Mixture	
Brown Waste (Carbon)	**Green Waste (Nitrogen)**
Dry leaves	Vegetable scraps / Fruit peels
Newspaper	Coffee grounds
Chipped wood	Houseplants
Dried grass	Manure from herbivores
Sawdust	Non-seeded weeds
Shredded paper	Hair
Wood ash	Feathers
Straw	Fresh grass
Peat moss	Hay
Pine needles	Tea leaves

Table 1: List of Compost Material

Besides deciding what and how much materials to use, maintaining a good moisture content within the compost pile is also important in producing the best possible compost. Compost progress is best at a moisture content of about 40 – 60% by weight, based on the information from [3]. If the moisture content is too high, the compost faces a high risk of becoming anaerobic. On the other hand, when the moisture content is too low, microbial activity is limited. If the pile is too dry and the temperature becomes too hot (above 65 ^{o}C), the compost can spontaneously combust, though this is a relatively rare event.

Following the input of materials, the container is then rotated from time to time. By rotating the container, the materials are properly mixed and evenly aerated. Aeration is imperative in maintaining the appropriate temperature at around 40 – 60 ^{o}C as stated in [1] (at higher temperature, the frequency of rotation needs to also increase in order to keep the temperature from getting too high) and allows for more microbes to survive, helping to decompose the materials faster and reducing odors. During this entire process, it is important to frequently verify that the moisture and temperature within the mixture is at a desirable level. The entire aerobic composting process, assuming that the compost is frequently mixed, can take as little as a month or two, depending on the C:N ratio and moisture content. After the process is finished, even if the compost appears to be ready, it is generally recommended to let the compost sits at a low temperature, keeping it moist and aerated, for a period of time so that the it can stabilize.

2.4 Requirements and Specifications

For this project to become the ideal efficient composting mechanism, it must follow a strict set of requirements and specifications. There are certain requirements that must be identified in each of the subsystems involved in order to fulfill the targeted design and development. This section is devoted to identifying requirements that the automatic composting machine must meet.

Table 2 lists the multiple requirements of the mobile application. It will eventually be used as a personal user interface for the user to monitor the status and functions of the operating system while physically being away from the actual device. This allows for a vast opportunity of application for the user.

#	Requirement	Reason
1	A mobile application will provide the user with remote access to the system.	This allows for individualization and customization of the compost.
2	The app shall provide the user with system information pertaining to the temperature, humidity, and power usage.	This keeps the user updated and informed on the status of the compost.
3	The user shall have access to all controls remotely through the app.	Gives easy access to control panel.
4	The app will display a graph of temperature vs. time throughout the entire composting process.	This keeps the user updated and informed on the status of the compost.
5	The app shall require a login password for access to each individual user's own machines.	This keeps the individual's information confidential and personal.

Table 2: Mobile Application Requirements

Table 3 lists the multiple requirements of the LCD display application. While still providing the user with a similar interface as the mobile application, the display allows for direct system access so the user doesn't necessarily need the mobile app to alter anything for the operating systems.

#	Requirement	Reason
1	The display shall produce a brightness of at least 300 lumens (cd/m2).	To be visible outdoors during the day and night time.
2	The display shall have a diagonal size of no less than 4.3" and no more than 7".	Allows for a large enough screen to be easily visible and fit the layout of the menu.
3	A capacitive touchscreen will be equipped for indoor applications while a resistive touchscreen will be equipped for outdoor applications.	This allows for a variety of environments for the screen to function in.
4	The display will draw no greater than 5V and no greater than 100mA.	This keeps the power consumption low and efficient.
5	The display shall have a minimum refresh rate of 60Hz.	To keep updated and accurate.

#	Requirement	Reason
6	The display shall show statistics about the machine/compost throughout various stages of the composting process to the user.	This allows for research analysis to understand the compost process better and how to adapt the system to narrow the process efficiency.
7	Controls shall be accessible through the display for manual operations.	Manual operations allow for the system to undergo and control automatic cleaning, loading, emergency stop, etc.

Table 3: LCD Display Requirements

Table 4 lists the multiple requirements of the microcontroller. This is vital to the operating system's functions because the MCU is essentially the brain of this device. This table explains the numerous features and functions that the MCU must communicate with in order for other devices to be commanded and function.

#	Requirement	Reason
1	The MCU shall be able to interface with at least two sensors (one humidity and one temperature).	To accurately track the temperature of the compost so that it stays within the desired range, as well as add/withhold water depending on how much humidity is in the pile.
2	The MCU shall have the capability to interface with more sensors besides the required two.	Due to the possibility of how large the holding container might become in the final design (not prototype), more sensors will be needed at different points within the container to accurately output the readings picked up.
3	The MCU shall be able to interface with an LCD.	So the user can visually see the readings of the sensors, as well as system messages.
4	The MCU shall be able to function normally in high temperature of around 50^{o}C at most over an extended period of time.	Since the system will be located outside in the sun, the MCU needs to be able to operate under such condition, at least for several hours.
5	The MCU shall be able to communicate with the mobile application to display sensors' readings and system messages.	Similar to its interaction with the LCD, the MCU also needs to send the information to the mobile application via wireless connection.

Table 4: Microcontroller Requirements

Table 5 lists the multiple requirements of the sensor applications. This table shows the standard needs that the sensors must have because of their application with monitoring compost or soil and the parameters that they must also meet in order to achieve this product's application.

#	Requirement	Reason
1	All sensors shall be weatherproof and non-corrosive to compost and bacterial material for at least a time period of several months.	To ensure that the sensors can withstand a long-term period of testing in the compost material's environment and not require any maintenance.
2	All sensors shall withstand an operating range of temperature of at least -10°C to +85°C.	This standard range of temperature shows that the sensors will produce accurate readings of the compost's aspects within the assumed temperature range that the compost undergo.
3	The sensors shall be compatible with the selected microprocessor.	To ensure compatibility and accuracy throughout the electrical system.
4	The sensors shall measure temperature and moisture with a small margin of error and be compatible to testing before system integration.	To ensure that the compost is measured as close to accuracy as possible as well as external testing to prove that the part is functioning properly.
5	Sensors shall have an operating voltage inputs of 3Vto5V.	To ensure that the sensors have low power consumption to keep the electrical system energy efficient.
6	A water sensor shall measure the level of water in the rainfall reservoir tank.	To ensure that there is accessible water for the system to utilize.

Table 5: Sensor Requirements

Table 6 lists the multiple requirements of the mechanical devices. These requirements are vital for the product's goals of self-sustainability and the production of compost. This list gives requirements that allow the operating system to function on its own without the use of any user inputted steps.

#	Requirement	Reason
1	The water cylinder shall contain enough water to control humidity for a 3-4 hour period.	This is to ensure that if dry material is placed inside that the water container has enough water to reach ideal levels.
2	The water pump and tubing shall be able to produce mist in the cylinder.	This will serve as the primary method in which to add moisture to the material.
3	The mixing system shall be able to mix material when the cylinder is 50% full.	This is one of the vital functions needed to occur to aerate the material.
4	The DC motor used to turn the cylinder shall be powerful enough to rotate the cylinder at a consistent pace for 6-8 hours.	This will keep the material loose and aerated.
5	The mechanical system structure shall be able to hold the temperature and moisture sensors in place while material is mixing.	This will enable accurate readings and monitoring of temperature and moisture.
6	The mechanical system shall not leak.	This is to contain any contamination into the surrounding area that the prototype sits.

#	Requirement	Reason
7	The mechanical system shall allow air to flow to the material inside.	This will ensure that the material is not going anaerobic and maintaining a stable amount of oxygen.

Table 6: Mechanical Requirements

Table 7 lists the multiple requirements necessary to power the system. Power requirements are essential to follow in order for the device to function properly without error or inability to electrically turn on. If any of the devices in the system were not supplied with the proper power components, the devices in the system would not all function properly and cause irregularity throughout the mechanism.

#	Requirement	Reason
1	The system shall be grid independent.	To reduce operation costs and be sustainable.
2	The system shall be able to power the prototype for 6-8 hours with no input from solar PV.	To ensure the prototype resembles field application.
3	The DC-DC conversion efficiency shall not drop below 85%.	To minimize losses and ensure maximum conversion from solar PV to load application.
4	The solar array mount shall be able to be adjustable.	To optimize PV array production efficiency based on its location and direction.
5	The power system components except for PV array shall be housed in a weatherproof space.	The final product will be placed outdoors and the prototype shall reflect that application.

Table 7: Power Requirements

3.0 Research
The design of the automatic aerobic composting machine was completed after much research into the following areas: existing products, power technologies, microcontroller technologies, display technologies, mobile application development, and sensor technologies. These will each be discussed throughout this section and will elaborate on the relevant details that affected the overall design. It should be noted that the topics discussed here are not comprehensive in both breadth and depth, yet references are given for further exploration into each area.

3.1 Existing Products
In today's market there is small competition for composting materials in general since most people choose to make and maintain compost piles through their own manual effort. This manual effort really drives competition towards the tools that aid in the manual labor. When it comes to automatic or semi-automatic composting solutions, the competition is even more scarce with most of the products aimed toward industrial sized solutions, leaving only a handful of companies that make products with automatic features.

3.1.2 Nature Mill
While most composting aids and solutions are designed for outdoor use, NatureMill's automatic composting machine is designed for both outdoor and indoor use with claims that it can even be put inside of a cabinet, under the sink for instance. This design is made up of two chambers: a top chamber and a bottom chamber. Food waste is added to the top chamber where it is aerated and mixed with sawdust pellets and baking soda. Once full, the waste is transferred to the bottom chamber which allows no new food waste to enter until the composting process is complete, which can take up to two weeks.

NatureMill offers three different versions of its automatic composting machine, the Neo (two gallons), Metro (three gallons), and the Ultra (four gallons). Benefits of the larger sized machines include not only a larger capacity but also quieter operation. All three feature a triple sealed lid with a hot carbon filter to keep odors and heat inside the machine. Price points for each of the machines respectively are $249, $299, and $399, making this one of the easiest and most cost affordable automatic composting machines offered on the market today.

3.1.3 Joraform
Joraform offers two categories of composting solutions: a manual tumble cylinder for outdoor home use and an industrial, automatic composting machine for restaurants or big businesses. The Jorakompost 125/270/400 are all part of the manual category and feature a cylinder split in half to create two chambers as shown in Figure 2. One chamber can be used to add new food waste while the other can be allowed to mature without the addition of new food waste. The cylinder is propped up off the ground through its center axis so that it can be manually rotated to allow for easy mixing of food waste and other added materials.

Figure 2: Jorakompost 125/270/400 (Used with permission from Joraform AB)

Joraform also is the maker of the Jorakompost 5100 and the Joraform Biocontainer which are industrial-size machines that create compost automatically after food waste is inputted. The Jorakompost 5100 is a 185 gallon, two chamber system, as shown in Figure 3, that allows fresh food waste to be inputted into the first chamber where it is mixed and aerated with high power rotating blades. After about two weeks this mixed waste is transferred to the second chamber where it is allowed to curate for another two weeks into a mature and usable compost. If used regularly, compost can be extracted on a regular basis every two weeks. This machine can also be programmed to alter or fine-tune the composting process to the users desire or needs.

Figure 3: Jorakompost 5100 (Used with permission from Joraform AB)

The Joraform Biocontainer is very similar to the Jorakompost 5100 in that it also is a two chamber system, is programmable to meet the users specific composting needs, and can also produce mature compost on a steady two-week time frame if used regularly. The main difference with the Biocontainer is that with its dimensions being 19'x7'x7' (LxWxH), as shown in Figure 4, it is designed for a very large scale operation such as at a hotel or a plaza where multiple restaurants might share use for the same composting machine.

Figure 4: Joraform Biocontainer (Used with permission from Joraform AB)

3.1.4 Ecoman

Similar to Joraform, Ecoman is a company with a variety of composting solutions based on the scale that is needed. The smallest of their automatic composting machines is the Ecoman Foodie Model F-03. It is a one chamber system where food waste is inputted and left to compost for twenty-four hours. Being the smallest model of the Ecoman Foodie, it only produces 1-3 kg of compost per day but remains a very competitive option for users that produce small amounts of organic waste.

3.2 Market Analysis

It is evident from section 3.1 that there are many solutions for those that are interested in turning their organic waste into a usable compost that can have a better impact on the environment than simply throwing away their waste. One example in section 3.1.2 provided within the category of manual composting tools is the Joraform Jorakompost 125/270/400. There are a myriad of such tools that aid the user in developing their own composting process. Downfalls of these solutions consist of maintenance and time. In order to use these products effectively the user must maintain a watchful eye throughout the entire composting process to make sure that the desired compost is being produced. This includes activities such as manually turning the compost pile, adding extra organic ingredients to reduce odors, and keeping track of the temperature to ensure the pile is reaching a high enough temperature to kill off any possible weed seeds. These products, though, are often much cheaper than their automatic counterparts and therefore are more appealing to the user who may not be able to make such an investment.

Looking into the field of automatic composting machines, it is clear that these systems best suit the needs of most people today. They require very little maintenance, are easy to use, and do not require detailed knowledge of the composting process from the user. This allows for broad use by anyone who is interested in turning their food waste into useful compost that can be used for fertilizing their own gardens and/or yards. One downfall of these products is the cost which the user must pay for all of these benefits. For instance, the NatureMill Eco series discussed in section 3.1.1 provides a very elegant automatic composting solution with many of the benefits of being simple, easy to use, and not requiring much knowledge except on simply how to use the machine. However, the cost for even the cheapest machine is a steep $249. Some users might see this as a deterrent to their composting efforts and therefore costs of this nature should be minimized to allow composting to be an uncomplicated and affordable pursuit. One way to solve this problem could be to encourage more companies to enter the automatic composting market for home users. Currently, there is very little competition for devices such as the NatureMill Eco series. Ecoman's Foodie discussed in section 3.1.3 is one other similar product that can be utilized by home users yet the competition seems to stop there. With more competition, prices could be driven down to entice users to their products.

The industrial field is one in which the most competition can be found. While the benefits of such systems are overwhelmingly positive, the targeted customers are acutely narrow: large restaurants, hotels, and theme parks. Only two companies were mentioned in section 3.1 that produce industrial scale automatic composting machines, however there are myriad other companies that provide the same type of solutions for large businesses and industries.

3.3 Relevant Technologies

Aside from the products that claim to have automatic features for composting, there are many other technologies involved with the design of the automatic aerobic composting machine. Areas that were researched include power, embedded applications, mobile applications, displays, and sensors. These all play an important part from providing power to the system to allowing the system to think on its own to providing an exceptional user interface.

3.3.1 Power Sub-System

This section goes into detail covering the various methods of technologies as they relate to power. Specifically, solar photovoltaic materials, DC-DC conversion circuits, charge controller types and battery technologies will be covered. The multitude of options will be compared on the basis of size, lifetime, cost, and efficiency.

3.3.1.1 Solar PV

With a remote system design that will be grid independent, the power system must be replenished by a source aside from the main grid. Solar energy is an energy source that can be captured in various ways such as photovoltaic and concentrated solar. For this project three varieties of photovoltaic technologies will be considered. The materials under consideration are monocrystalline, polycrystalline and thin-film. Table 8 below represents a high level comparison between the three types presented.

Monocrystalline solar panels have a higher efficiency percentage than its polycrystalline or thin-film counterparts. This is due to the purity of the silicon it is created from. There are many differences in manufacturing processes, however, the decision of which company to acquire the solar panel from will also need to be considered as actual efficiencies may vary. Monocrystalline cell efficiency is 25.6+/- 0.5% [18]. Due to the increase in overall efficiency of these types of panels, the end user will need less surface area compared to the other two materials/technologies to achieve the same power output. Another characteristic that stems from the purity of the silicon ingot is the lifetime of the panels. From this website monocrystalline panels have a lifespan of 25-35 years. From this page, Monocrystalline silicon (mono-Si) output percentage of power will degrade at a rate of 0.47 percent per year for systems installed prior to 2000 and at a rate of 0.36% per year for systems installed after 2000. Because of the higher purity, the cost of the monocrystalline is generally more expensive than the other options as well. The actual cost will be determined by the specific power requirements of our system and the size of the panel needed.

Due to its less pure nature, polycrystalline is less efficient than monocrystalline. Also, in higher temperature climates the efficiency suffers more than the monocrystalline material. From this website, polycrystalline cells have an efficiency range of 18.4%-20.8%.With a lower performance efficiency, The system or mounting location would need to have a larger surface area to produce an equal output than that of a monocrystalline setup. Polycrystalline panels have a lifespan of 23-27 years. From this page, polycrystalline silicon output percentage of power will degrade at a rate of 0.61% per year for systems installed prior to 2000 and at a rate of 0.64% per year for systems installed after 2000 [19]. Because less pure silicon material, the cost of the polycrystalline is generally less expensive than the monocrystalline cells. This is also due to a simplified manufacturing process with less material waste. Through an online search of various size panels, the price per watt for polycrystalline panels is <$1-$3.50. Our actual cost will be determined by the specific power requirements of our system.

Thin-Film technology is less efficient than both monocrystalline and polycrystalline. Higher temperature climates do not affect the efficiency as much as monocrystalline or polycrystalline materials. Thin-Film cells have an efficiency range of 7%-15% [19]. With a lower performance efficiency, the installation site would need to have a larger surface area covered to produce an equal output. Thin-Film panels have a lifespan of 10-15 years [19]. Thin-Film silicon output percentage of power will degrade at a rate of 1.44 percent per year for systems installed prior to 2000 and at a rate of 0.96 percent per year for systems installed after 2000 [20]. Due to a simplified manufacturing process with less material waste, the cost of Thin-Film is substantially less. The price per watt for Thin-Film panels is $1-$3.50 [21]. Our actual cost will be determined by the specific power requirements of our system.

	Monocrystalline	Polycrystalline	Thin-Film
Efficiency	25.6 +/- 0.5%	18.4%-20.8%	7%-15%
Space Requirement	Least	Middle	Greatest
Lifetime	25-35 Years	23-27 Years	10-15 Years
Cost	Greatest	Middle	Least

Table 8: Overview of three types of photovoltaic materials

3.3.1.2 Charge Controller / DC-DC Conversion

This section considers the different types of charge controllers and DC-DC conversion technologies. The charge controller will be connected in between the solar panel and the battery storage and will optimize the power flow from the solar panel to the battery. For the charge controller design, there are two major types, one is Maximum Power Point Tracking (MPPT) and the second is Phase Width Modulation (PWM). DC-DC conversion will take place between the loads and the battery and will ensure that the loads are powered with the correct voltage and current allowances. The three types of DC-DC conversion topologies assessed will be Buck, Boost, and Buck-Boost. A summary of the three types of DC-DC circuitries are shown in Table 9.

Using a MPPT system is an electronic way to optimize solar panel output in order to connect to the grid or charge a battery system more effectively. This system will sense the battery bank voltage and adjust the output current and voltage from the solar panel(s) to charge the batteries in the most efficient way. Normally the current is what is optimized so the battery system can charge in less time since optimal daylight is only occurring during a few hours each day. An MPPT takes in the DC from the solar system, converts it to AC to adjust the voltage and current, then converts the AC back to DC with the optimal current and voltage to be used when charging the battery system. A MPPT charge controller system has a reduced cost as compared to an analog system as most of the calculations and adjustments are made using a microcontroller or semiconductor device with a build in MPPT algorithm. These electronic versions will also reduce error and possibility of diversion of the MPPT. Using a preprogrammed duty cycle to ensure the microcontroller is taking multiple iterations of measurement, the MPPT can be constantly readjusted and optimized to approach within 90% of the maximum power point.

A PWM system is an effective alternative to MPPT charge controller designs. The primary difference is that PWM keeps a constant voltage and varies the current. This system monitors the battery storage systems age, state, and other conditions. A PWM system is recommended in warmer climates since the voltage output of the panels generally drop in these conditions so current is the more viable output to monitor and control. Additionally, in low power applications, a PWM system is more effective than a MPPT. A PWM system will be able to effectively keep batteries charged and at the charging level recommended. For a PWM system, it is recommended that the output voltage of the solar array matches closely with that of the recommended battery system voltage since the PWM will bring down the voltage of the solar array to best match the battery system. If the solar array has surplus of voltage produced, that power will be lost as heat when used in a PWM system.

With many devices being powered from the battery bank, the voltage must be increased or decreased to ensure the loads are properly powered and operating successfully. Circuits that have these characteristics are called Boost and Buck converters. In some circumstances, there can be a combined circuit that has both Buck and Boost capabilities called a Buck-Boost Converter. One of the primary characteristics considered will be efficiency. Due to the system's dependence on a battery system with no grid connection, the power being transferred from the batteries to the load must be as efficient as it can be. Not only does the DC-DC conversion affect the load, but if it is not efficient, then the storage capacity and solar input must be increased to compensate for the need for more power. Efficiency is a vital consideration as it clearly effects the scale of the entire power system.

A Buck converter's primary purpose is to reduce the input voltage to a lower voltage level. It is highly efficient and loses minimal heat when stepping down voltage. The circuit can be implemented in a continuous mode or discontinuous mode which provides flexibility when and how we choose to implement the device it is stepping the voltage down for. The overall board size is minimal and leaves room for other components in the PCB and storage container design. Finally, the efficiency of Buck converters is 90% or above which is vital to an energy conservative focused system design [23]. Although clearly stated, this design can only reduce a voltage. This comes as a drawback only because if implemented, the source would always need to be greater than the desired output of the converter. Another key disadvantage is the noise on the output of the circuit and the need for a possible filter across the input. Finally, the circuit does not have isolated inputs and outputs. This means that we would need to ensure proper precautions are taken to protect other board components both on the high and low sides.

A Boost converter has one primary function and that is to increase a DC voltage from a lower level to a higher one. When this is done, power is conserved and the current is in turn decreased as a result of the stepped up voltage. Relative to a Buck converter, this type of circuit does not require as many components to control output ripple so in general the footprint is smaller. Utilizing a Boost converter has the potential to also reduce battery storage size since the voltage needed on the load side can be met by the Boost converter. This type of space saving feature would enable a device to be more portable and have less weight due to battery storage. In using a Boost converter, there are drawbacks such as increase in heat produced and noise on both the input and output. Additionally, with regards to the current being higher on the input side, all of the components on the front end must meet the max current requirements and may add additional cost to the circuit.

A Buck-Boost converter combines the features of both a Buck and Boost converter. This is used in applications where the input voltage may go above or below the required output voltage. Many times this type of converter is used in mobile electronics as the battery voltage may begin higher than the output but then as the charge is diminished, the voltage drops as well. This type of converter enables for a more robust system to be designed since it is set up to deal with a variety of input voltages yet still provide the required output voltage. In this scenario it is possible to get the most out of the power supply as this will ensure the output remains constant for as long as it can. Downsides with using a Buck-Boost converter is that it would require additional components than if the design only utilized one or the other type of circuit making the system less robust in the long run.

	Buck	**Boost**	**Buck-Boost**
Pros	Greater Efficiency, minimal loss to heat, continuous or discontinuous mode	Less components	Capable of both reduction and increase in voltage with steady output
Cons	Always needs greater input voltage than output, noise across the output, non-isolated I/O	Requires lower input than output voltage, increase in heat produced, higher current on input adds to cost for robust materials	More components, increase in board space, increase risk for component failure

Table 9: Pros and Cons of the three DC-DC converter variations

3.3.1.3 Battery

This section considers the different types of battery technologies. Batteries are an integral piece to this system because it will act as the sole energy storage device. In the marketplace there are a diverse variety of battery technologies and chemistries. In this section lead acid, lithium ion (Li-Ion), and flow cell battery types will be discussed and compared. Table 10 will summarize the positives, negatives, and cost of each battery type assessed.

Lead acid batteries have been around since they were invented in 1859. This class of batteries have two primary types with two different purposes. The first is a "Starter" type that is designed to have a burst of high output current but not sustain steady load demand. This type of battery is usually used to start a vehicle or piece of equipment. The other is a "Deep Cycle" that is meant for steady continuous output. Applications for this type of Lead Acid battery are golf carts, and electric tools. Lead Acid batteries are powerful and can provide a high power output. They can also provide power in high and low temperature environments where Lithium Ion batteries are not as dependable. These types are easy to find in multiple voltage ranges and Amp hour ratings. They are very heavy and not environmentally friendly. If not charged or cycled well they will lose life expectancy. Additionally, they take an extended period of time to charge. To maximize life, they must not be cycled 30% less than capacity [22]. These battery types are generally less expensive than all other options but replacement and durability must be considered.

Lithium Ion batteries have a few different specific chemical variations but overall they are a more energy dense storage device than other options on the market. With this density they are found in more mobile devices like cell phones or laptops. With the greater energy stored in a smaller package, less space would be needed to house the. In mobile applications, this feature is important and a positive attribute. Also, this chemistry has more cycles so the Li-Ion option could be a longer lasting medium if the system will be cycling often. The primary downside to Lithium Ion technology is the cost and scalability. Additionally, the functional temperature range is more restrained than other technologies. The cost of Li-Ion systems is much greater than that of Lead-Acid types. It may be a better consideration depending on the specific application of the storage system and the rate and frequency of its cycling.

Flow batteries utilize an electrolyte liquid that holds the charge. There is a membrane that enables electricity to flow from one medium to the other. This potential difference is what drives the power to the load. The flow cell battery technology is scalable, longer lasting, and has the potential to be used in the kilowatt and megawatt level. The system is simple but would require more attention than that of your average battery. The cost is still not feasible on a small scale and the components of the system besides the electrolyte may prevent ease of distribution and construction. The overall controls would need to be monitored and optimized. Large scale systems are more realistic in the market today. Relative to lead acid and lithium ion technologies flow cell batteries are more expensive.

	Lead Acid	Li-Ion	Flow Cell
Pro	Can provide power in high and low temperatures, capable of high power output, two varieties for two applications	Energy density, longer lasting if cycling often	scalable, longer lasting, grid level storage potential
Con	Heavy, require maintenance/monitoring, cycling limitations	Cost and Scalability	Price, parts and material distribution
Cost	Least expensive, frequency of replacement must be considered	Greater than lead acid	Greater than Li-Ion and lead acid

Table 10: Comparison of Lead Acid, Lithium Ion, and Flow Cell Batteries

3.3.2 Microcontroller

A microcontroller is the main control component of an embedded application. There are many different microcontrollers available in the market, each designed for different uses. Deciding on which microcontroller would fit best for the composting system greatly depends on the types of operations the system will be doing, and if the microcontroller offers the features that can satisfy the needs of the system.

3.3.2.1 Features

Some microcontrollers focus on delivering the general features that an embedded application will need, with an emphasis on ultra-low power consumption. Others prioritize having as many superior features as possible while attempting to conserve the power usage of the microcontroller. This section will discuss some important features of microcontrollers and the requirements that the composting system will need in order to function properly.

Due to the composting system being powered by solar energy, the unit has to be positioned underneath constant sunlight, running the risk of possible overheating of the system. Because of this, the microcontroller, as well as other hardware units, need to be able to withstand high temperatures. Assuming that the composting system will be exposed to strong, constant sunlight for at least five hours (as some days are sunnier than others), the microcontroller needs to be able to function under at least 50 ^{o}C, and possibly as high as 70 – 80 ^{o}C since it will be inside an enclosed space. High temperature also affects how much current the microcontroller will consume so it is highly important to consider how hot the microcontroller can get and take measures to decrease the chance and frequency of the system experiencing such high temperature.

The microcontroller should offer enough memory for the composting system to contain all the instructions it needs to operate effectively. On top of that, there should also be enough room for extra instructions that might come up during the planning process. The system will also need to store a certain amount of data, such as sensor and compost information from the previous cycle(s), to show the differences in the final products between the different cycles. Saving this information also allows for the system to show the user how the composting has been progressing over time.

The composting system will need to communicate with more than ten external peripherals. Thus, the system requires a microcontroller that offers a good number of pins and supports the standard embedded communication protocols such as UART (Universal Asynchronous Receivers/Transmitters, SSI (Synchronous Serial Interface), SPI (Serial Peripheral Interface), and I^2C (Inter-Integrated Circuit). These protocols will be covered in more details in section 6.2.2.

Microcontrollers offer a varying number of pins, and a set number of them (depending on the microcontroller) are GPIO (general-purpose input/output) pins. GPIO pins are very versatile in the sense that they can be configured to be either input or output pins with specific functionality. As an input port, it can be used to communicate ON/OFF signals from switches, or digital readings from sensors. As output port, it can be used to command external operations based on CPU instructions, such as commanding the motor or water pump based on calculation results. This is the reason why these pins are referred to as "general purpose". The intent is to pick a microcontroller with as many pins as possible after taking into consideration of other requirements, as having more pins will allow for easier up-scaling. Also, it allows for more leeway as there is always a possibility that extra external devices will be needed.

Since the composting system will be using analog sensors to monitor the condition of the compost, microcontrollers that comes with ADCs are preferred over ones that do not have them. In order for the system to read data coming from the sensors, ADCs are a must-have as microcontrollers cannot interpret the analog signal that the sensors output. Digital sensors could be used as an alternative, but they tend to be more expensive. Having the ADCs integrated into the microcontroller means that extra board space can be saved, either to minimize the size of the board, or to use that space for other ICs.

Considering that the system will be utilizing a motor to rotate the mixing container and aerate the compost pile, PWM is another feature that the microcontroller needs to have. PWM is used to control the voltage going into a device. Thus, it can be applied to manage the rotation speed of a motor or the brightness of an LCD display. It can also control the volume of an audio, as there is a good chance that the composting system will utilize an audio warning system.

3.3.2.2 Microcontroller Comparison

After careful reviewing of the available microcontrollers in the market, there are three series of microcontrollers that offer the most beneficial features for the composting system. This section shall discuss the individual series and their unique characteristics. There will also be a direct comparison between the common features between the three series.

MSP432P4x is a part of the popular MSP430 family that combines the different characteristics of the MSP430 such as low-power functionality and advanced mixed-signal features with the high-performance processing capabilities of the ARM 32-bit Cortex M4F CPU. This series is a good choice for when the embedded application requires a microcontroller to have the capability of performing enhanced low-power operations and efficient data processing. Table 11 presents a list of key features and description of each feature for the MSP432P4x series.

Features	Descriptions
Floating Point Unit (FPU)	- This is one of the features that put the MSP432P4x a little above the other series in the MSP430 family since most operates using fixed point arithmetic and cannot handle float values
Digital Signal Processor (DSP) Extension	- The job of the DSP is to receive real-world signals that are digitized, process the information, and return the output for real-world uses - An example of this is the MP3 player. Analog audio goes in as input during recording, is converted to digital through the use of an Analog-to-Digital Converter (ADC), and then passes into the DSP. The DSP then encode the information and store the file to memory. During playback, the file is taken from memory, decoded by the DSP, and is outputted as analog through a Digital-to-Analog Converter (DAC)
Low Power	- 95 microamps per MHz - Wake-up from Standby Mode in less than 10 microseconds

Table 11: Key Features of the MSP432P4x

The TM4C12x series makes use of the 32-bit ARM Cortex-M processors that provide high connectivity, low-cost, and ease of use. Unlike the MSP432P4x series, the TM4C12x is equipped with a high level of connectivity and sensor aggregation, which makes it an ideal choice for connected applications. Even within the TM4C12x, there are different types of microcontrollers. This section shall discuss two series that have the features necessary for the composting system.

TM4C123x Series: USB + CAN MCUs

The TM4C123x assimilates the ARM Cortex-M4 CPU with single-precision floating-point core that can function at up to 80 MHz and high-performance ADCs while only consuming little amount of power. The series also provides up to 40 PWM, or Pulse Width Modulation, outputs which are used to process signals, a good number of serial communication peripherals, USB OTG, or On-the-go which allows the MCU to act as a host for other USB devices to be connected to it, and two CAN controllers. Table 12 presents a list of key features and description of each feature for the TM4C123x series.

Features	Descriptions
Floating Arithmetics	- Floating-point functionality built into the core processor
Controller Area Network (CAN) Modules	- 2 CAN modules that use CAN protocol version 2.0 part A/B with up to 1 Mbps - CAN is a multiplexed serial communication channel where data is transferred to other electronic modules. It is quite similar to the SPI protocol, but more complex - CAN 2.0A protocol is an 11-bit identifier that provides good message throughput and good latency times. It also uses less silicon overhead - CAN 2.0B protocol is a 29-bit identifier that allows for more information transferred than CAN 2.0A protocol, but it requires more bus bandwidth. CAN 2.0B also increases the silicon cost and decrease the efficiency of bus usage

Features	Descriptions
Quadrature Encoder Inputs (QEI)	- Up to 2 QEI - QEI detects position and speed of rotating motion systems
Pulse Width Modulation (PWM)	- Up to 40 PWM outputs - PWM is used to vary voltage, which can be used for sound output, light dimming, and motor control

Table 12: Key Features of the TM4C123x

TM4C129x Series: ENET + LCD MCUs

The TM4C129x is the first ARM Cortex-M4 microcontrollers with built-in Ethernet MAC + PHY functionality, allowing the users to make new highly-connected products that can boost the fast-paced growing of the Internet of Things (IoT). TM4C129x is capable of running at 120 MHz CPU speed, provides a variety of connectivity options such as on-chip data protection, and a built-in LCD controller which saves board space. It also allows for connected applications like IoT gateways, linked home/building automaton controllers, connected human-machine interface (HMI), networked sensor gateway, and more. Table 13 presents a list of key features and description of each feature for the TM4C129x series.

Features	Descriptions
Floating Arithmetics	- Floating-point functionality built into the core processor
Control Peripherals	- 1 QEI or none at all - Up to 8 PWM outputs
10/100 Ehternet MAC + PHY	- Can transmit at either 10 or 100 Mbps - Uses IEEE 1588 protocol - IEEE 1588 protocol is the Precision Time Protocol (PTP), which allows for time synchronization between different nodes within the same network

Table 13: Key Features of the TM4C129x

The focus thus far has only been on the individual microcontroller series and their unique features. A more in-depth look at the similar features that all three microcontroller series share is needed in selecting the right microcontroller. Therefore, table 14 will show a list of common features among the three microcontroller series and compare the similarities and differences between them.

	MSP432P4x	TM4C123x	TM4C129x
CPU	ARM Cortex-M4F	ARM Cortex-M4F	ARM Cortex-M4F
Frequency (MHz)	48	80	120
Flash Memory (KB)	256	256	1024
SRAM (KB)	64	32	256
Operating Temperature (^oC)	-40 to 85	-40 to 105	-40 to 105
UART	4	8	8
SSI / SPI	8 SPI	4 SSI modules	4 SSI modules with Bi-, Quad-, and advanced SSI support
I^2C	4	6	10
GPIO	84	~120	90
USB	N/A	USB 2.0 OTG/Host/Device	USB 2.0 OTG/Host/Device
CAN	N/A	2 CAN A/B Controller	2 CAN A/B Controller
Ethernet MAC	N/A	N/A	10/100 Ethernet MAC
Advanced Motion Control	N/A	16 PWM outputs 2 QEI modules	8 PWM outputs 1 QEI module
ADC	14-bit, 1-MSPS SAR ADC	Two 12-bit ADC modules, 1-MSPS	Two 12-bit ADC modules, 2-MSPS
Analog Comparator	2	3	3
Digital Comparator	N/A	16	16
JTAG / SWD	4-pin JTAG 2-pin SWD	1 JTAG module w/ integrated SWD	1 JTAG module w/ integrated SWD
Package	LQFP NFBGA VQFN	LQFP BGA Microstar Jr.	TQFP BGA
Voltage	3.7	3.3	3.3

Table 14: In-Depth List of Features of the Microcontrollers

3.3.3 Display Technology

The market today is filled with a myriad of display solutions for presenting information to the user. Some of the more well-known brands are Newhaven Display, Electronics Assembly, Microtips Technology, and Sharp Microelectronics. These companies each offer a variety of displays with different features that prove to be beneficial to many products that need screen for presenting information. We will look here at the different features and discuss the benefits each one has to offer.

A major feature of any display that must be considered is the brightness that can be achieved during regular operation. Generally, the brightness of a display has a positive correlation with the size of the display as well as the pixel density. Therefore, a number of factors must be included in the search for adequate brightness. Since LCD technology will be used, a larger sized display is desired so that maximum brightness can be achieved. This will allow for the display to have more pixels and a larger backlight which in turn will provide a better user experience for a product that is operated outdoors most of the time. One final aspect when determining the correct brightness is considering the amount of ambient light that will be present while the display is being used. For a composting machine, it is evident that on any given day of use the sun will be shining and therefore produce very high ambient light. In this situation, screen brightness is highly attenuated from the combination of high screen reflection and a low contrast ratio. If high screen brightness is desired even in situations of high ambient light, a display with low glare and a high contrast ratio should be sought after.

Touchscreen capabilities are another feature that are implemented in many displays today, especially within the smartphone and tablet market. This rising popularity has driven interest in having touchscreen displays in other products too such as TVs, computer monitors, and various other niche products. In order to provide an intuitive and seamless interface to the user, adding a touchscreen interface is almost necessary. There are currently two types of touchscreen technologies being used today: resistive and capacitive. Resistive touchscreen displays operate through a bend in the display. Two layers are needed so that as the user applies pressure to the screen the two layers will make contact. A matrix layer of spacers in between the two layers, as well as the controller, then detect the change in current running through the display and will translate this touch into a set of co-ordinates for the software. Capacitive touchscreen displays are provided in two variants: surface capacitive touch and projected capacitive touch. A surface capacitive touchscreen uses one conductive coating with electrodes at each of the four corners that measure the electric field throughout the display. When the user presses on the display (human skin is conductive by nature) a change in the electric field is produced and the controller then uses information from each of the four electrodes to provide co-ordinates of the touch. Projected capacitive touch uses two layers each with a micro-grid of fine wires that produce a capacitance between each parallel location. The controller then can measure this capacitance and detect any changes among each individual location since they are independent of one another.

There are many benefits to each type of touchscreen technology with each having better applications toward different uses. Resistive touch displays are well known for applications where simplicity and lower costs are desired. They are also used when different types of material are expected to make contact with the display besides just a human finger (gloves, stylus, fingernails, etc.). One of the cons of resistive touch displays is that only one input can be detected at a time, therefore multi-touch gestures will not be recognized. With capacitive touch displays comes a better user experience simply due to the fact that the user does not have to put any pressure on the screen for a touch to be registered. However, it requires that a conducting material to register input and therefore causes special equipment to be used if the user wishes to utilize the display without direct contact with their finger (silver threaded gloves, conducting stylus, etc.). One major benefit of projected capacitive touch is that multiple inputs can be registered at the same time and therefore allow multi-touch gestures to be programmed into the display such as pinch-to-zoom.

3.3.4 Mobile Application Development

One of the most important aspects of the composting machine will be how the user interacts with the system. Two avenues will be provided: a display connected directly to the system and a mobile application for indirect access. This section serves to show all the aspects considered when designing the mobile application where key components include usability, simplicity, and efficiency.

3.3.4.1 Android

The mobile environment for Android devices is one that features the largest market share of products according to netmarketshare [10]. Figure 5 shows that Android devices make up roughly 60% of the market share for mobile operating systems. This makes developing for the Android operating system an appealing endeavor and can result in more users having the ability to access the mobile application for the automatic composting machine. With Google as the owner of the operating system, the developer has peace of mind knowing that their application will not become obsolete very quickly due to the large corporation and popularity that surrounds such a company as Google.

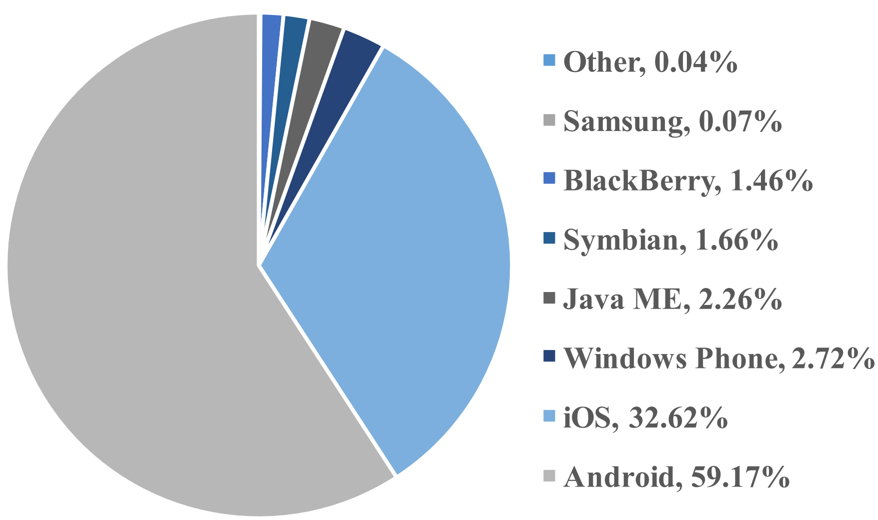

Figure 5: Mobile Operating Systems' Market Share

Although the Android market has the largest share compared to any other operating system, a significant con is shown with Android's fragmentation. Practically any specification that can be viewed on smartphones and tablets today can be exploited by Android devices to show the vast fragmentation for that technical specification. Looking at different versions of the operating system itself shows how great a divide there is between the latest version and older versions. Figure 6 shows that the most current version of Android (Marshmallow 6.0) is only installed on 4.6% percent of all Android devices [12]. This fragmentation causes challenges for the developer who desires that their application be available to as many Android users as possible with support for the features that come with the most recent operating system updates. More information on Android fragmentation in the categories of screen size, phone hardware/performance, and devices themselves can be found on OpenSignal's website [9].

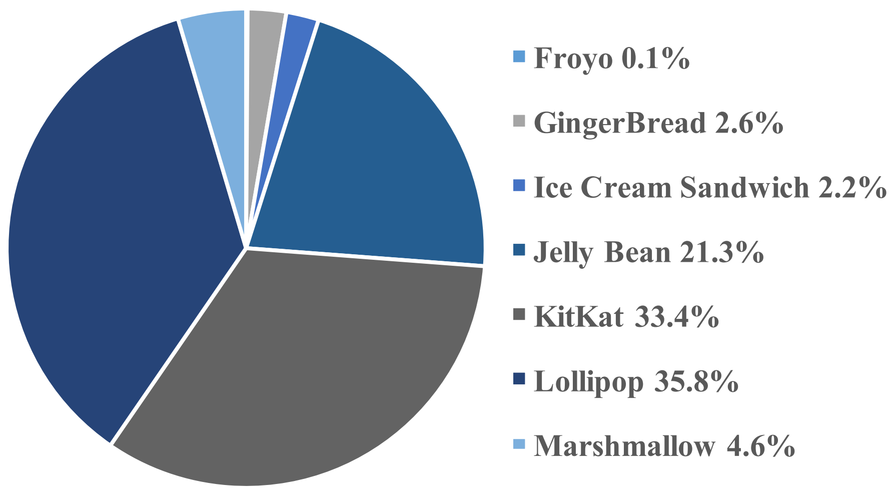

Figure 6: Android Fragmentation

3.3.4.2 iOS

Apple Inc.'s ecosystem for mobile applications is highly exalted in the iOS platform. Like Google, developers can take comfort in Apple's size and popularity knowing that their applications will be in existence for many years before becoming obsolete or needing significant updates. There is high competition for mobile applications within the iOS environment with over 1.9 million apps available on the US App Store as reported by International Business Times in an article written by Jerin Matthew [11]. This high concentration makes it challenging for developers to create applications that stand out from the rest and can grab the attention of App Store users.

Although the competition is fierce, developers have a higher chance at reaching more users due to iOS' low fragmentation. Figure 7 shows that the latest version of iOS (iOS 9) is running on roughly 84% of all iOS devices which is a sharp contrast to that of Android's Marshmallow operating system. With this knowledge, developers can know for certain that their applications will reach the vast majority of iOS users and in turn potentially reach more users within the market.

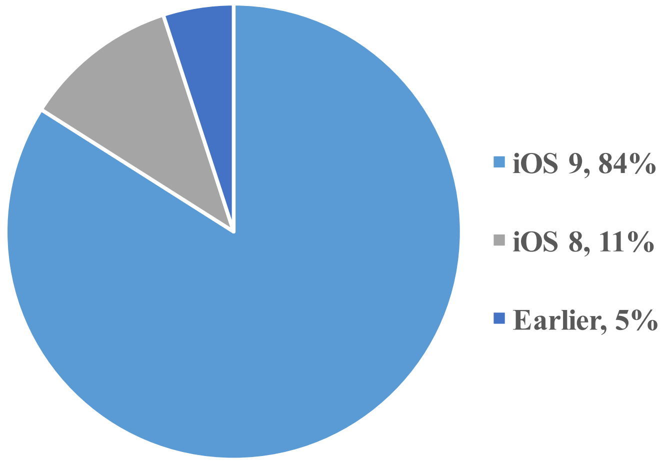

Figure 7: iOS Fragmentation

3.3.4.3 Developing Tools

Another perspective in the mobile application world looks at the tools that are available to the developer for creating and maintaining their application. These tools differ between Android and iOS and therefore will be used as comparisons throughout this section. Tools of most importance are available APIs (Application Programming Interface), programming languages used, IDEs (Integrated Development Environment), and device simulators.

APIs created from Apple's and Google's operating system are inherent with each version release. These take advantage of abstraction to provide building blocks to developers so that they can more quickly create their desired functionality within their applications without worrying about the details of how those building blocks are implemented. One area of importance with the automatic composting machine is wireless communication. iOS provides multiple APIs, such as the Core Bluetooth Framework and the Multi-Peer Connectivity Framework, that are simple to use and do not require a steep learning curve to implement in the developer's application. Android also provides multiple APIs, however, the issue of fragmentation discussed in section 3.3.4.1 plays a factor here where APIs available in more recent versions of Android may not be available for those using older versions of Android.

Programming languages offer up a smaller piece of the comparison of developing tools between Android and iOS. This is mainly due to the fact that both of the languages used are based on object-oriented concepts and therefore share many similarities with the only difference found in syntax. Android is based on Java which is a well-known and popular language with ample support from many third party sources. It is taught in most schools as the language of choice for expressing object-oriented design and is fairly easy to grasp. iOS on the other hand uses an Apple crafted language called Swift. Based on the previously known Objective-C (also hand crafted by Apple) Swift uses many of the same object-oriented concepts and wraps them in a very convenient and user friendly syntax meant to protect the developer from many unwanted errors that come very easily with Java. However, the syntax is drastically different and will most likely be unknown to most developers.

IDEs and device simulators make a developer's job much easier and more cost effective if designed well. With IDEs there are a myriad to choose from on the Android side since Java is a very popular language. This allows each developer to choose their favored IDE for coding in Java and still be able to produce the same application as another developer using a different IDE. The iOS platform is not as diverse with only one main IDE available for developers to conform to: Xcode. Cons of this IDE are that it is the only way to produce a pure iOS application and can only be run on a Macintosh computer which can be a steep expense for most developers. However, Xcode has been favorably reviewed by many iOS developers as simple and elegant to use, providing much needed support for beginning developers while also allowing more experienced developers to take advantage of it's powerful features.

These IDEs are connected to device simulation software that allows developers to test their applications using their computer's hardware. This gives developers the power to test their applications without having to pay the price for their application's target device. Though Xcode may be the only major IDE available to program on for iOS applications, one appreciable feature is the iOS Simulator which runs very smoothly on Macintosh computers and can emulate all of Apple's iOS devices. The integration with Xcode and Mac OS X yields a beautiful environment for accurate testing of mobile applications. The same cannot be said for Android applications, where testing through device simulators and emulators can be hindered by the Java runtime environment. This disconnect between mobile application and computer hardware causes lag and complex customization options.

3.3.4.4 User Interface

Every developer must spend a substantial amount of time creating a user interface that will be intuitive and simple to navigate. With this comes graphics that imply to the user how the navigation of the application works (through arrows, tabs, etc.), buttons to allow different controls, and messages/alerts to provide the user with useful information. Android and iOS applications handle user interfaces in a similar fashion through input controls, navigation, and general layout. It is important with a mobile application for the automatic composting machine that setup be simple and fast with information being almost immediately available to the user. Since many similarities exist between the two platforms discussed, it is left to the reader to examine the articles provided by each faction [13], [14].

3.3.4.5 Communication Platforms

Using a mobile device to communicate with other networked devices is becoming more and more popular with the advance of the IoT(Internet of Things) network. The general idea is that devices and objects should include software and hardware that allows them to collect and exchange data. The inclusion of this peripheral to the mobile application will provide an enormous resource of data and control to the user. There are two main channels that allow this communication to flow: Bluetooth and Wi-Fi.

With Bluetooth comes benefits of low energy usage and reliable connectivity that most people are familiar with. Almost all available smartphones that accept mobile applications come with Bluetooth capabilities that use the same protocols no matter what device or operating system they're running. However, Bluetooth operates on a very limited range of 100 meters meaning gathering information onto a mobile device would require the user to be in the vicinity of the composting machine. This would have use for an outdoor system where the user may want to check on certain information from their composting machine or want to control it while they are inside their home. Any distance away from the user's home would leave the range of the device and therefore could not be utilized by the user.

Wi-Fi allows this range to be extended to practically any networked location on Earth. The composting machine could therefore connect to the nearest Wi-Fi network and transmit data to the user's mobile device about it's operation. The user in turn would also be able to send commands and control the machine from vast distances and be able to receive alerts in real time. These benefits come with a seemingly smaller drawback that delays in communication between the mobile application and the composting machine would be significantly greater since data would have to travel through the network of an ISP instead of traveling directly to the mobile device as with Bluetooth technology.

3.3.5 Sensors

The following subsections discuss research related to the multiple sensors and the different methods of measuring their respective aspects that are necessary to monitor the composting system. These subsections entail a variety of ways to measure varying features that directly correlate to the composts' health. Multiple options for each type of sensor is explored, elaborated, and described in full detail.

3.3.5.1 Temperature

Measuring temperature is extremely important in the composting process. The range of temperature that the compost undergoes determines whether the bacteria lives or dies. Not only is it a determinant of life or death and health of the compost, but it can also be utilized to optimize the compost process if supervised and adjusted properly so that the bacteria thrives in the most ideal conditions. In order to monitor the temperature of the compost, further research was invested to examine multiple options. There are several ways of measuring temperature and this varies in digital thermometers by generating voltage or resistance output values. The digital thermometer's multiple types have varying aspects depending on the application, desired response time, and accuracy. A description of their general benefits and features can help determine the most suitable contact sensor type.

Resistance temperature detectors (RTDs) generate varying resistance values. RTDs work by producing a predictable resistance at a given temperature. Resistance wire RTDs have a positive coefficient by increasing resistance with temperature increase. The hotter they become, the higher the value of their electrical resistance. Platinum is the most commonly used material because it is nearly linear over a wide range of temperatures, is very accurate, and has a fast response time. RTDs can also be made of copper or nickel, but these materials have restricted ranges and problems with oxidation. RTD elements are usually long, spring-like wires surrounded by an insulator and enclosed in a sheath of metal. Advantages of RTDs include their stable output for long periods of time and easy calibration Disadvantages comprise of a small overall temperature range, high initial cost, and a less rugged design.

Thermocouple sensors generate an output signal of varying voltages. The different metal and alloy combinations in the thermocouple's legs produce a predictable voltage for a given temperature. The metal legs generate a net thermoelectric voltage between the opening according to the size of the temperature difference between the ends. A temperature reading is made by calibrating the device with known temperatures, placing one of the metal junctions on another material of a known temperature and the other on the object whose temperature needs to be identified. The voltage displayed is read using the calibration formula from which the temperature of the object can be calculated. These type of sensors are accurate, operate well at very high temperatures, and are highly sensitive to small changes in temperature making it easier to respond quickly to any environmental deviations. However, the device can encounter errors over an extended period of time due to corrosion that affects the thermoelectric voltage. Thermocouples are also inexpensive and well-suited for making automated measurements given their lifetime period. The Thermocouple Type-K is a simple combination of two sensitive metals and is relatively inexpensive costing at around $10. It has a simple digital 2-wire interface that measures about 1 meter in length. The sensor requires an amplifier such as MAX31855 that outputs a digital signal to the microcontroller. This dependency on the amplifier is so the voltage output can be translated to a digital signal that the microcontroller can understand and use. This requires another part to be researched and invested in to integrate into the system.

This specific type of sensor converts the analog temperature measurements into a digital output of calibrated signal all within the device. There is less chance of error occurring from noise disturbance and thus a high level of accuracy in the electrical signal because of the digital sensors independency from the microcontroller. The *DS18B20* is a digital temperature sensor that correlates temperature readings to 9 to 12-bit Hexadecimal codes and converts that to a digital word all in 759 ms. The sensor has a 1-wire interface, in which there is only one pin required to communicate with the microcontroller and no external components. Because each *DS18B20* contains a unique silicon serial number, multiple *DS18B20s* can exist on the same bus. The microcontroller's communication on a single wire bus can be accomplished by addressing each different sensor by its serial number. This feature allows for placing temperature sensors in many different places in the mixing container and monitoring the temperature throughout the compost as long as sufficient power is supplied [32]. This product uses Arduino's software code design and the hardware consists of UNO, a *DS18B20* sensor, and cables to connect the sensor to the MCU. The three port accessibility provides an input voltage source, ground, and data line that allows for simple integration as well. The sensor chip can be protected with a high quality stainless steel tube encapsulation that is waterproof, moisture proof, and also prevents rust. The sensor has an operating range from -55°C to +125°C (-67°F to +257°F), which easily covers the necessary range of temperatures that the compost will endure.

3.3.5.2 Moisture

Due to the affect that water has on the quality of compost, the system will need to monitor the moisture content of the material throughout the composting process cycle with the use of a sensor. It is important that the sensor is durable and operates within the parameters that the compost and mixing mechanism will endure to continuously take data of the soil-like and compost material. The two ways to measure soil moisture is by measuring moisture tension or moisture content. Soil moisture tension tells you how easy it is to extract water from soil. When a soil is saturated, there is plenty of water in the pore spaces and plenty of water coating the soil particles. Soil moisture content tells you how much water is in the soil representing what percentage of total 'volume' of soil is moisture. Both ways are informative, resourceful, and unique. There are many devices and sensors that record moisture tension or content in a variety of ways including dielectrics, microwaves, and radio waves. One of the most common is to calculate water tension through porous material like gypsum blocks or tensiometers. A customary way of finding moisture content is utilizing the dielectric constant or dielectric permittivity of material.

A type of sensor that measures soil water tension is a gypsum block, also called an electrical resistance block, measured in kilopascals. The porous block is placed on top of the soil and must maintain firm contact with it. The block contains two embedded electrodes into which wires are inserted. The other ends of the wires penetrate the soil surface. As water moves through the block to maintain equilibrium with the soil moisture, the electrodes measure the electrical resistance that the water generates. The drier the soil, the greater the electrical resistance and vice-versa. A portable meter converts the resistance readings to water tension values and sends that signal to the data logger. While advanced, the use of a simple resistance or ohm meter to read the electrical resistance blocks will not provide stable or reliable readings. At a normal farm site, a gypsum block may last 2 to 3 years, but in areas of frequent irrigation it may require annual replacement. And with the risk of such frequent maintenance, price of the system must be taken into account. The blocks can range in price from $6 to $35 each and meters cost $250. With the need for multiple blocks and multiple replacements over long periods of time, this form of measurement turns out to be quite expensive.

The SEN0193 soil moisture sensor, as shown in Figure 8, measures moisture levels by capacitive sensing rather than resistive sensing like other sensors on the market. It is made of corrosion resistant material which gives it an excellent service life. The part which is below the warning line won’t get rusty because it has oil ink on the surface. Only the exposed components will get rusty, which requires attention to design details. This is easily resolved by designing a protective plastic material to package the components and only keep the parts which are below the warning line in the soil and water. This module includes an on-board voltage regulator which gives it an operating voltage range of 3.3 ~ 5.5V. It is perfect for low-voltage MCUs like the one this compost system will operate from. This sensor is compatible with a which can be directly connected to the Gravity I/O expansion shield that protects the wires [26]. The software this sensor uses is Arduino's design and the hardware consists of UNO, a capacitive soil moisture sensor, and jumper cables to connect the sensor to the MCU. The three port accessibility provides an input voltage source, ground, and data line that allows for simple integration as well.

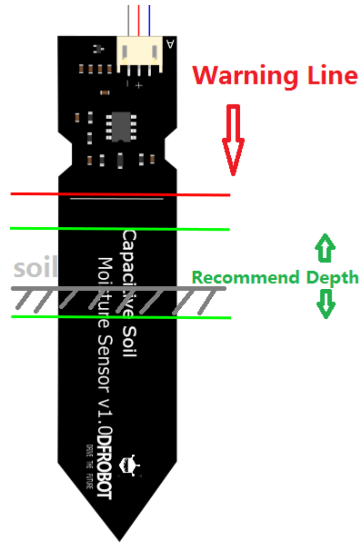

Figure 8: SEN0193 Capacitive Soil Moisture Sensor

3.3.5.3 Water Level

Measuring the water level of the reservoir tank can be achieved in many different ways. Devices could measure the capacitance and correlate it to distance using floats or magnetism that follow the water surface, or they could use transmitters and transducers to detect the distance from the water. Useful transducer output signal formats for computer automation are current loops, analog voltages, and digital signals. Analog voltages are simple to set up and work with, but may have serious noise and interference issues. 4-20 mA current loops (where the loop current varies with the level measurement) are the most common output mechanism today. Current loops can carry signals over longer distances with less degradation. Digital signals coded in any of a number of protocols are the most robust, but older technologies can only handle limited distances. New wireless capabilities can be found in the latest transmitters' signals, allowing them to be sent over tremendous distances with virtually no degradation. Given all of these various options, none are quite as reliable as the more advanced technology in sonar or waves. More advanced measurement technologies, like ultrasonic, radar, and laser, entails more sophisticated digital encoding formats that require digital computer intelligence to format the codes. Combining this requirement with the need for advanced communication capabilities and digital calibration schemes explains the trend toward embedding microprocessor-based computers in virtually all levels of measurement products.

The ultrasonic method of fluid lever measuring is a contactless method that measures distance between transceiver and fluid shown in Figure 9. Short ultrasonic pulses are transmitted and the travel time of that pulse from transceiver to liquid and back to transceiver is translated into its distance. Ultrasonic pulses first travel through air and bounce off liquid because of the change of density from air to water. Because water has higher density, the majority of pulses will bounce off. Due to the pulse length, there is a small window that cannot receive pulses because the transceiver is already busy transmitting. The simple solution is to place the sensor higher than the maximum water level by a few centimeters allowing the receiver to start operating. Also, if the tank diameter is too small, the signal could bounce off of the tank's walls and cause false readings. TI has a $70 kit of microcontrollers plus an extra $12 for transducers to build an ultrasonic water level monitor.

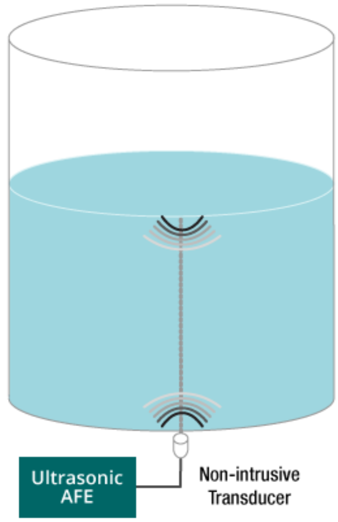

Figure 9:Ultrasonic Transceiver In Water Level Application (Used with Permission by Engineered Plastic Products Corporation)

Laser Level Transmitters are designed for bulk solids, slurries, and opaque liquids such as dirty sumps, milk, and liquid styrene. Lasers operate on a principle very similar to that of ultrasonic level sensors: instead of using the speed of sound to find the level they use the speed of light as shown in Figure 10. Using light as the medium of measurement rather than sound allows for a faster response time. A laser transmitter at the top of a vessel fires a short pulse of light down to the process liquid surface, which reflects it back to the detector. A timing circuit measures the elapsed time and calculates the distance. The key is that lasers have virtually no beam spread (0.2° beam divergence), no false echoes, and can be directed through spaces as small as 13 cm^2 [27]. Lasers are precise even in vapor and foam. They are ideal for use in vessels with numerous obstructions and can measure distances up to 457.2 m. These glass windows must pass the laser beam with minimal diffusion and attenuation and must contain the process conditions.

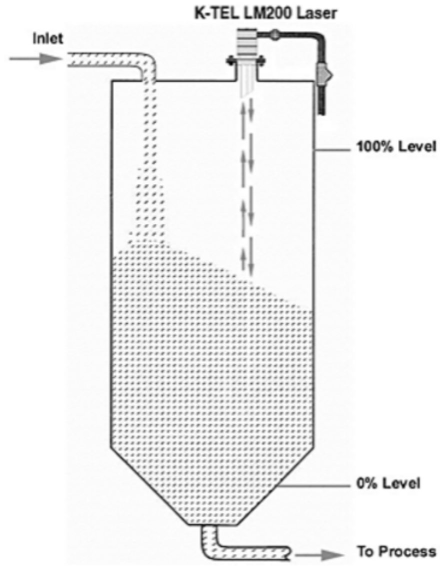

Figure 10: Laser Level Transmitter In Water Application (Used with Permission by Engineered Plastic Products Corporation)

GP2Y0A41SK0F is a distance measuring sensor unit, composed of an integrated combination of PSD (position sensitive detector), IR-LED (infrared light emitting diode) and signal processing circuit. The variety of the reflectivity of the object, the environmental temperature, and the operating duration are not influenced easily by the distance detection because of adopting the triangulation method. This device outputs the voltage corresponding to the detection distance which ranges from 4 to 30 cm. The sensor has a low operating supply voltage of 4.5 to 5.5 V while functioning in a reasonable outdoor temperature range of -10 to +60 C. Its features and qualities allow the sensor for use in a low power MCU and simple integration with just three ports for Vcc, ground, and output voltage as shown in the Figure 11.

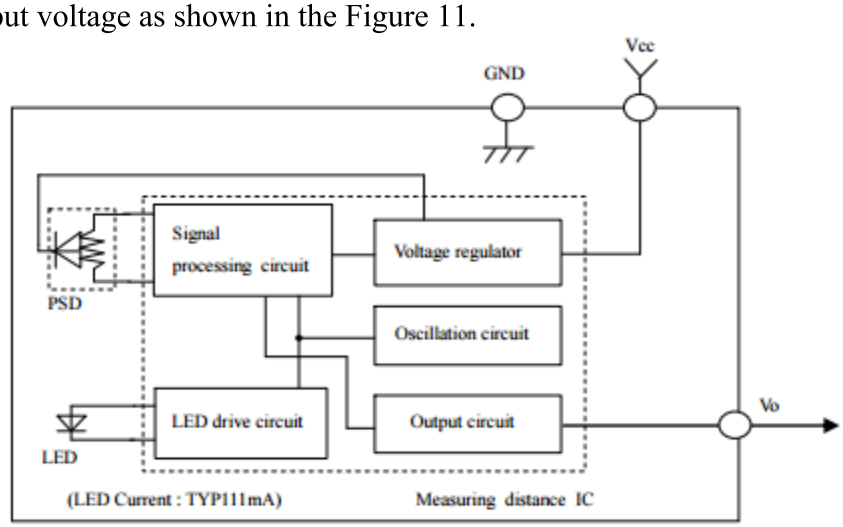

Figure 11: Infrared Light Emitting Diode Circuit (Used with Permission by Sharp)

4.0 Related Standards

In order to speed up development and promote compatibility the AACM design adheres to multiple standards. Using standards allows for a consistency of certain features to be prevalent throughout multiple parts. These standards help in the design decisions made by organizations before us.

RS232 is a recommended standard that defines serial communication in hardware and software applications between two connected devices. The RS232 standards contain voltage, pinout, and cabling standards for this serial communication. Most Wi-Fi boards on the market also make use of RS232 communication standards to send and receive information from the microcontroller processor and memory subsystem. The microcontrollers in this project use UART (universal asynchronous receiver/transmitter) for communication with multiple devices like temperature and moisture sensors, motors, water pumps, etc. The UART module bases its design on the RS232 communication standards to communicate over a USB port. UART uses a single data line for transmitting and one for receiving data. Microcontrollers must agree on the transmission speed, or the bit-rate, in order to have communication synchronized.

The scope of the IEEE 802.11-2012 standard is to define one medium access control (MAC) and several physical layer (PHY) specifications for wireless connectivity for fixed, portable, and moving stations (STAs) within a local area. The purpose of this standard is to provide wireless connectivity for fixed, portable, and moving stations within a local area. This standard also offers regulatory bodies a means of standardizing access to one or more frequency bands for the purpose of local area communication. These standards define several PHY signaling techniques and interface functions that are controlled by the IEEE 802.11 MAC and permits the operation of an IEEE 802.11-conformant device within a wireless local area network (WLAN) that may coexist with multiple overlapping IEEE 802.11 WLANs. It also assists in the description of the requirements and procedures to provide data confidentiality of user information and MAC management information being transferred over the wireless medium (WM) and authentication of IEEE 802.11-conformant devices.

The IEEE 2700-2014 Standard for Sensor Performance Parameter Definitions creates a standard guideline for sensor technologies to follow. This protocol, created by Kenneth Foust and his working group, is necessary in the vast expansion of sensor and microelectromechanical Systems (MEMS) [28]. Sensors are the core sources of technologies that help improve people's lives everywhere in the world. IEEE's standard is intended to provide a common methodology for specifying sensor performance in the ever-growing and innovative sensor technologies of the consumer electronics industry. This standard allows for simpler, non-scalable integration that manufacturers normally would have had a challenging time with. Not only does sensor technology vary in vendors, but in types as well. Various types of sensors require specific terminology, framework, units, conditions, and limits to be designed and developed. IEEE 2700-2014 standards apply to many types of sensors like accelerometers, magnetometers, gyrometers/gyroscopes, barometers/pressure sensors, hygrometers/humidity sensors, temperature sensors, ambient light sensors, and proximity sensors. The use of this standard allows for a commonality that unifies variations of sensors to be used together in a system.

Standards for chain and sprocket shapes and sizes exist for easier integration and manufacturing in systems. The system will be using the ANSI Standard Roller Chain No. 35. Chain and sprocket designs are based off several factors, like pitch length and the diameters, width, and length of the part's features. This system uses a chain and sprocket connection to rotate the main drum container for the compost to aerate. The sprockets designed must meet the standard dimensions to fit the selected No. 35 bushed chain as shown in Figure 12. the Dimensions for this standard chain size can also be shown in Figure 13.

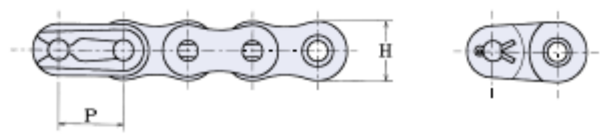

Figure 12: No. 35 Bushed Chain (Used with Permission by IEEE)

35 (BUSHED CHAIN)

SY Chain No. (ANSI)	Dimensions - mm											Average Ultimate Strength	Maximum Allowable Load※	Average Chain Weight
	Pitch	Bushing		Pin					Plate		Trans. Pitch			
		Width	Dia.	Dia.	Length				Height	Thick.				
	P	W	R	D	L_R	L_C	L_1	L_2	H	T	TP	kN	kN	kg/m
SY35	9.525	4.78	5.08	3.58	12.0	12.9	6.0	6.9	9.0	1.25	–	10.8	2.48	0.34
SY35-2					22.1	23.0	11.1	11.9			10.1	21.6	3.67	0.63
SY35-3					32.2	33.1	16.1	17.0				32.4	5.40	0.92
SY35-4					42.3	43.2	21.2	22.0				43.2	7.13	1.22
SY35-5					52.4	53.2	26.2	27.0				54.0	8.42	1.56
SY35-6					62.5	63.5	31.3	32.2				64.8	9.94	1.89

Figure 13: Chain No. 35 Size Dimensions (Used with Permission by IEEE)

5.0 Design Constraints

When designing an application, multiple constraints are required to be addressed in order to effectively produce a successful product. This section shall explore the mentioned constraints and how they affect the final design of the composting system, and propose solutions to overcoming those obstacles. There are two major areas of constraints that this prototype must consider in its design. The topics covered include economic, manufacturability, sustainability, environmental, health, and safety. Relating to economics, it is important for this design to be cost effective. Manufacturability considers the ease of production and assembly. Both of those factors are constrained by sourcing materials and following practices that are sustainable. Once a final prototype is constructed, the operation, breakdown, wear and tear, and disposal of components must be considered as they affect environmental, health, and safety. The life cycle of the product involves the sourcing of the raw materials and the end use of the disposed prototype. Each and every step along the way needs to be considered against these two categories of constraints.

5.1 Economic, Manufacturability, Sustainability

The current design of the composting system will only be a miniature version of the actual size that would be needed for optimal compost production. Therefore, the price of the system is likely to increase if it were to be up-scaled to a larger model. The target market consists of universities and normal households; thus the goal is to create an affordable system that can compete with the composting machines that are available in the current market. By increasing the size of the product to achieve the optimal speed for compost production, a possible cost constraint could arise that might hinder the success of the product. One possible solution is to use the cheapest available materials to have the cost of the system as low as possible while still keeping the system functioning at an optimal throughput. The composting system has the potential of being implemented in many universities and households as long as considerations are made during manufacturing. The use of highly-available parts is a definite must, as the waiting and searching time for less popular parts could prove to be detrimental during the assembly phase. Also, the continuous advancement of technology as new parts become popular should also be considered as old ones become obsolete and could possibly go out of production. The most time-consuming tasks that will likely affect the manufacturability of the system are designing the PCB and assembling the mechanical system. Designing the PCB for the first time will consume more time, though afterward, the only thing that is needed is to simply follow the design and steps to get there. This same process also applies to the software portion. Therefore, in order to reduce the production time and to maximize the manufacturability of the system, steps shall be taken to follow the fastest and simplest method in producing the system, making it possible to quickly and easily replicate.

Since the system will be positioned outdoor under constant sunlight, solutions to the problem of materials and parts overheating are a must-have for better sustainability of the system. The control system, especially, might need its own cooling device to prevent overheating. Although this will not be as big of a problem since the selected microcontrollers can function in extreme temperature. Strong wind and rain must also be taken into consideration, as these will be the toughest obstacles for keeping the system sustainable. Not much can be done on the developers' side in this matter besides providing warnings the end users on how to maintain the machine. Also, the system can be made to be easily transported over a short distance to be relocated under shelter from harsh weather. Besides temperature and weather, poorly-made design can also worsen sustainability through the possibility of short circuiting or having no prevention of electrical surges to the system.

5.2 Environmental, Health and Safety

In consideration of the system design, the prototype must consider constraints as they relate to the areas of environmental, health, and safety. This planet is one which needs protection from some of humankind's activities. Various products that include electronic devices, motors, solar panels, and battery storage, the chemical properties and manufacturing processes of each are some of the major constraints to pay attention to.

When selecting electrical components, it is important to pay attention to semiconductor devices that are RoHS compliant and lead free. These are meaningful constraints for the environment because the device will be designed to live outside where it is exposed to weathering and extreme conditions. This type of environment will place added stress on the various materials and possibly cause the components to mix with rainfall that could lead to ground contamination. It is for this reason that the electronics shall be housed in a sealed, weather proof container and select the most environmentally friendly materials of that container in order to minimize any chance of contamination in nature. Additionally, the system shall ultimately be designed to take waste and produce usable material that can be added to land and mixed in with soil. Because of this process and application, the system will be designed to ensure that key composting indicators are being monitored and recorded. The end user shall be able to trust that the finished compost product can be safely used and applied on lands or gardens where it is needed.

As it relates to health, the mixing cylinder must withstand expected temperatures and not release any chemicals and not mix with the material or the surrounding environment. If this constraint is not met, there is the potential for contaminants to enter into the soil and in turn be enveloped in the food chain, possibly contaminating sources of food and water. Aside from the mixing container materials contaminating the material, there is the risk of producing unfinished compost which could have a negative effect on soil health and if applied to a food producing garden, could bring about pests and vermin. With pests and vermin come the potential for pathogens to be ingested and lead to illness. It is in the best interest of this design to produce a prototype that can be used to produce stable and safe compost.

Safety is and always will provide key constraints that cannot be ignored. In this design there will be a system that contains a power system, moving parts, and various electronics. The final prototype needs to be fully capable of housing the key functional components safely and prevent a user from being exposed to any risk. The electronics and power system components must be housed in an enclosure that will restrict accidental access from a user. Additionally, the enclosure must prevent excessive moisture and temperature levels to make sure that no component can overheat and fail, causing a fire, or potential harm. Proper maintenance and care is necessary when utilizing a battery. Depending on the battery technology utilized, the temperature inside the enclosure should not exceed the operating temperature of the battery, which if not controlled could result in an explosion. Considering the various electronics powered by the battery, a PCB needs to be designed that correctly converts the voltage and current to the desired level. If the paths on the board are designed too close, and not properly tested to prove their viability, there could be a short that could cause fire or failure in the power system. When designing the PCB, minimum space separation of each path needs to be exceeded to reduce any chance of such a failure. The system needs to be designed considering all specifications and requirements of each component used to stay safely within operating requirements of all components.

5.3 Ethical, Social, Political

This prototype design must consider constraints as they relate to ethical, social, and political arenas. Each of these, although dynamic in nature, must be considered as the design is developed and the prototype moves through this Senior Design process. This design will have the ability to assist in reducing future amounts of waste tonnage to landfill and help to decrease the volume of harmful gasses that enter Earth's atmosphere. Because of the control system having the ability of reducing these unfortunate side effects, the system is within the bounds of ethical constraints.

In the social arena, the constraints may vary from location to location and from culture to culture. Due to these considerations the constraints discussed are focused mainly on the social constraints of Orlando, FL, specifically Orange County. In Orange County there are many land owners and those who produce a respectable amount of food and yard waste year round. Many of the Orange County constituents do have an appreciation for reducing their carbon and waste footprint and would be interested in becoming a user of this technology. The social atmosphere is leaning towards a more sustainable way of living and is supportive of the composting effort and encouraging the design and implementation of this type of prototype.

In the political sphere, rules and regulations vary depending on county, city, state, and country. Considering Orlando as the selected area for application, composting is gaining lots of momentum and attention from the city. It is against the law for an unlicensed individual to transport waste in a vehicle. Due to this constraint, the system needs to be self-sufficient and operate in any individual's yard or outdoor location. This could enable the end user to be able to walk their available yard and food waste to the machine and immediately begin making compost without the need to transport their material elsewhere. The city of Orlando has recently begun providing free compost bins to its residents to help reduce the percentage of compostable material sent to landfills. Although effective in gaining social support, the device is basic and leaves the composting process and pile maintenance up to the end user. This program led by the city has given us a constraint on where the design will need to differ and show that the prototype does not interfere with the program. Also, the system must make sure that the composting process utilized is in accordance with the policies set in place locally. Additionally, policies and regulations do change with time, so as the design and prototype is developed, the latest statuses need to be considered. This system may not require the transportation of waste further than someone's own back yard, so it may be able to align with the current constraint. Additionally, if the rules were to change to allow the transportation of waste by citizens, the prototype could still be within legal bounds. The device provided by the city is quite large, although since the process is not optimized, there could likely be a less than optimal amount of waste actually being drawn from landfills. This system, with the use of optimization and control techniques enables more waste to be diverted to become compost in less time removing more potential material from landfill sites. The other side of the policy area is the standard and requirement of producing Grade A compost. Grade A compost must have been held at minimum temperature of 50 degrees Celsius for at least 72 hours. This constraint is present to ensure that all possible weed seeds and pathogens have been broken down and will not lead to soil contamination when the compost is applied to various land applications. This prototype and design needs to consider these constraints and accomplish this task to comply if used in commercial activity.

6.0 System Design Details

An important question that needs to be addressed for any system is how the system will be designed. A system contains various subsystems, and within them, different components working together to produce the required functionalities. For the composting system, these components encompass peripherals such as microcontroller, water pump, motor, LCD, battery, sensors, and etc. Thus far, the document has considered several viable options for each of these components. This section now shall explore more in-depth the options that best satisfy the requirements of the composting system, and how the components will be designed to interact with one another.

6.1 Power System

A mobile power system is one that is not connected to the main grid. This configuration can also be referred to as “grid independent”. It is self-contained and is responsible for all of its power requirements. On a high level it is comprised of three major components: solar panel, storage, and the load.

To connect the panel to the battery and the battery to the load, DC/DC converters are utilized. The main consideration when designing and implementing these components is efficiency. The more efficient the system, the smaller the battery and solar panel can be. This is important as it conserves space and reduces cost. When connecting the solar panel to a battery, a charge controller is utilized. There are two primary types of charge controllers, however this system will utilize a PWM design. The charge controller has a vital role in maximizing the output of the solar panel enabling a faster charge time for the battery system. The circuit configuration and logic will implement three general modes of operation that will maximize the longevity of the battery and its health throughout its useful life. When connecting the battery to the load side, there will be DC/DC converters in place to ensure that the devices requiring power are receiving the correct voltage and current. Due to this prototype having different load side voltages, there will be separate DC/DC converters in place to step up or down the battery voltage to the correct level. Depending on the efficiency and level of voltage change, the number of components required will vary. When designing a printed circuit board (PCB), board space is an important consideration as well as overall number of components. Throughout the DC/DC conversion section, the difference between a 5%-10% in efficiency may mean a difference of 200 components and a steep change in cost. These kinds of considerations will need to be reflected in the design.

Depending on the current draw of the system at various voltages, the battery will need to be sized accordingly to power the system for a long enough duration for its application. The battery specifics will be noted in 6.3.1. With batteries, it is important that the contacts are well maintained and minimum corrosion is built up. This could affect the overall performance of the power flow and in turn reduce the longevity of the prototype. Additionally, the battery charge levels must be well maintained to keep the battery as healthy as possible. Poor maintenance of batteries can result in premature replacement and add unnecessary costs to the system as a whole. This is an unsustainable practice for a system that is intended to be left without human interruption for extended periods of time.

As discussed in the section 3.3.1.1, solar panel types vary and so do their efficiencies. In this system, efficiency and cost play a role but efficiency is a more important consideration. This is because the amount of time needed to charge the battery will directly reflect the power output of the panel and its ability to convert sunlight into usable energy. If the system is under load and requires continuous power in a specific circumstance, the panel will be the bottleneck in maintaining system operation. Table 23 presents the comprehensive bill of materials for the entire Power sub system.

6.1.1 DC-DC Conversion Design Details

For the prototype's DC-DC conversion circuit design and development, Texas Instrument's WEBENCH® was utilized. In this design, the selected storage source was a standard 12V sealed lead acid battery. However, the specific amp-hour rating was selected based on the results of the efficiency of this DC-DC conversion circuitry. If this circuit were to be less than 100% efficient, the supply would need to have more storage to power the loads for the required duration. Additionally, the initial current value that is vital to battery selection could only be determined once the DC-DC conversion circuitry and components were selected. The battery specifics will be further discussed in section 6.1.3. For this prototype, Table 15 shows each device that requires electricity and power from the battery unit. In Table 15, the devices are grouped together by common voltage levels. This is important as future information described will be based on this. With common voltage levels, the entire DC-DC conversion will only require three different switchers, or DC converters. With three buses, the total bill of materials will be reduced as compared with a circuit that requires more voltage levels to be accounted for.

Qty	Part	Nominal Voltage	I Max (Current, Amps)	Power (Watts)
1	Wi-Fi Controller	3.3	0.42	1.386
3	Temperature	5	0.002	0.01
3	Humidity	5	0.035	0.175
1	IR Receiver	5	0.6	3
1	IR Emitter	5	0.05	0.25
1	MCU	5	0.113	0.565
1	DC Motor	12	1.5	18
1	Water Pump	12	0.4	4.8
1	Fan	12	0.3	3.6
			Total Power:	31.786

Table 15: Powered Devices in AACM Prototype

With the decision of using a 12V deep cycle lead acid battery, the details of cycle use and standby use were now determined. Due to the fact that the loads may not always be in use, both the lowest value from the standby use category and the highest value of the cyclic use category were utilized. The main reason why those values range in general is because the battery when fully charged will be at the higher end however, as the battery is depleted, the voltage level drops. From that source stems all of the loads as shown in Table 15. Depending on heat, runtime, and other variables, the current draw may increase to the loads. To ensure that each device is able to receive its required current, some values, as shown in Table 16 (WEBENCH® load specifics), show that the current required is higher than what is shown in Table 15. During normal operation the current required may not reach that level. The margin needs to be present so that if the current draw does increase, the design of the DC-DC conversion and the PCB paths are suited to provide the optimal current needed. Not only is current considered but the accuracy of the voltage output is key as well. To ensure that each load is receiving as close to optimal voltage as possible, each load was determined to receive no greater than 5% variation in its voltage required. This value could have been made larger, which could have reduced part count and cost, however if made smaller, the bill of materials and number of components would have increased. Five percent showed a balanced compromise between bill of materials, parts total, and overall system efficiency. With the battery voltage level range identified, as shown in Table 17, and the load data entered from Table 16, the next step is to generate the schematics using the WEBENCH® program.

Load #	Load Name	Voltage (Volts, V)	Current (Amps, A)	Vout Ripple (%)
1	Wi-Fi Controller	3.3	0.5	5
2	Humidity #1	5	0.04	5
3	Humidity #2	5	0.04	5
4	Humidity #3	5	0.04	5
5	IR Receiver	5	0.6	5
6	IR Emitter	5	0.1	5
7	Temperature #1	5	0.002	5
8	Temperature #2	5	0.002	5
9	Temperature #1	5	0.002	5
10	MCU	5	0.15	5
11	DC Motor	12	1	5
12	Water Pump	12	1	5
13	Fan	12	1	5

Table 16: Parameters Entered into WEBENCH

With the information from Tables 16 and 17 loaded into the WEBENCH® program, the software then generates the overall schematics of the DC-DC conversion. This prototype is comprised up of three different voltage conversion stages to provide the proper voltage and current for various loads. Some buses only have one load, and another has eight. Each stage is optimized for each load connected to its output. At this point, the user can select to change overall system efficiency and reach the level of performance needed to meet the requirements of the circuit. For the purposes of this prototype, the efficiency could have been anywhere over 80%. As efficiency approaches 100%, the number of components and system cost increases dramatically. While finding the most reasonable nexus, the efficiency of 89% was achieved with only 54 components, and a $7.62 overall cost.

Voltage (V)		Calculated Current Max (A)
Minimum: 8.0	Maximum: 15.0	10.0

Table 17: Preliminary Battery Characteristics Input into WEBENCH

With the high-level design and values selected, now the specifics must be introduced. The Texas Instrument's WEBENCH® program provided a complete table that outlines the specific DC-DC conversion components used and their respective performance details. This info is shown in Table 18. Since majority of the load voltages are below the battery output voltage levels, it enables the configuration of DC-DC conversion to be efficient. A high-level display of all seven DC-DC stages and schematics are shown in Figures 14-19. With the information provided from Table 18, the total current draw expected during maximum and "all on" operation can be calculated. With this information, the charge controller design can now be selected.

#	Name	Part Number	Description	Vout (V)	Iout (A)	Efficiency (%)
1	SUPPLY_1	TPS562200	Switcher : 17V, 2A, 6-pin, Low Iq Synchronous buck converter with Advanced Eco-mode	5	1	93.3
2	SUPPLY_2	TPS562200	Switcher : 17V, 2A, 6-pin, Low Iq Synchronous buck converter with Advanced Eco-mode	3.3	0.5	90.2
3	SUPPLY_3	MP1584	Switcher : 28V, 3A, 8-pin High-Efficiency step-down regulator with an integrated internal high-side high voltage MOSFET	12	3	85

Table 18: DC-DC Converter Characteristics Input into WEBENCH

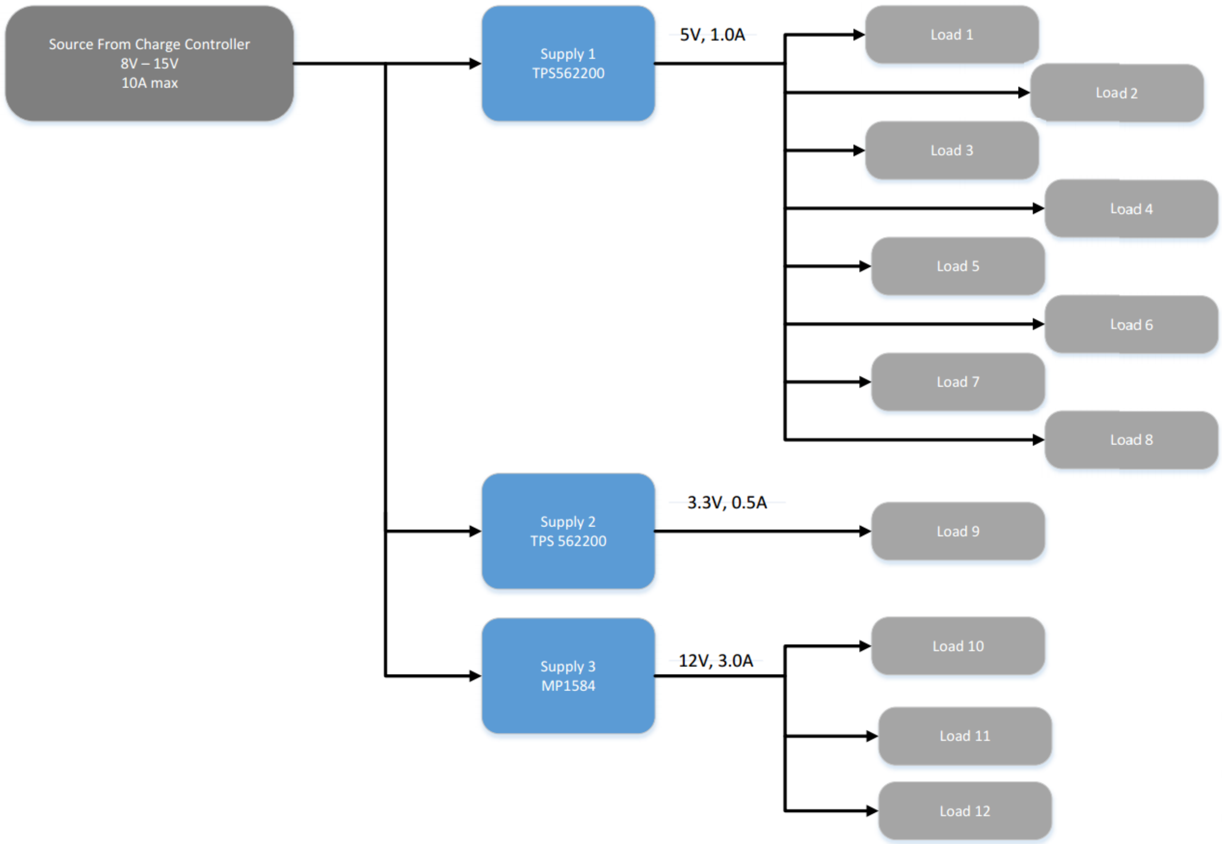

Figure 14: Overall DC-DC Conversion Layout

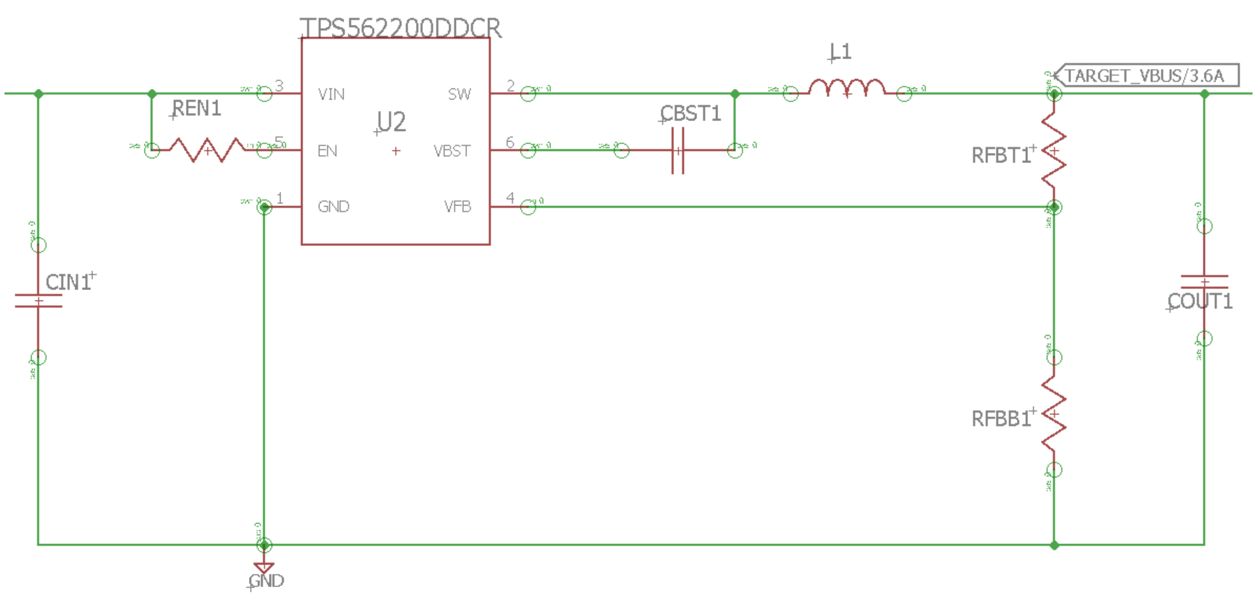

Figure 15: Supply_1 Schematic

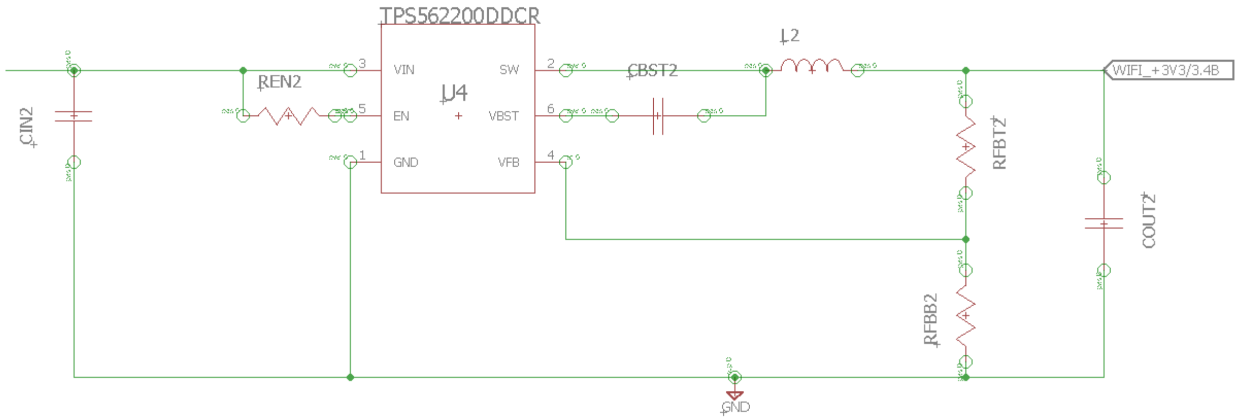

Figure 16: Supply_5 Schematic

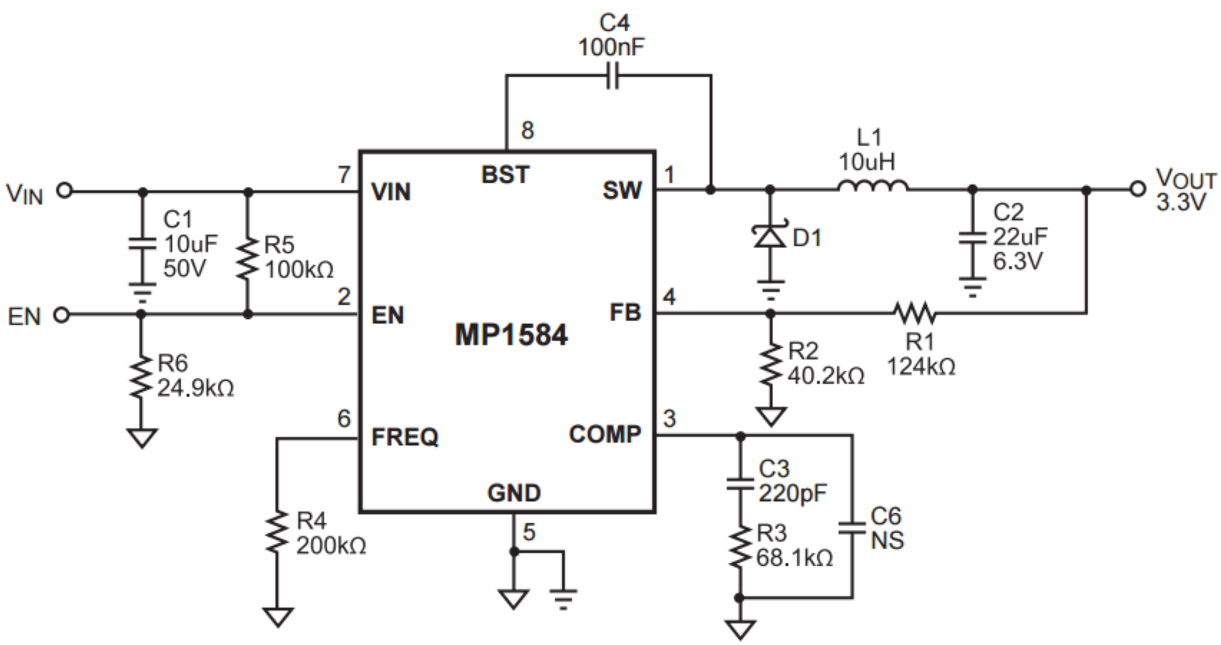

Figure 17: Supply_6 Schematic

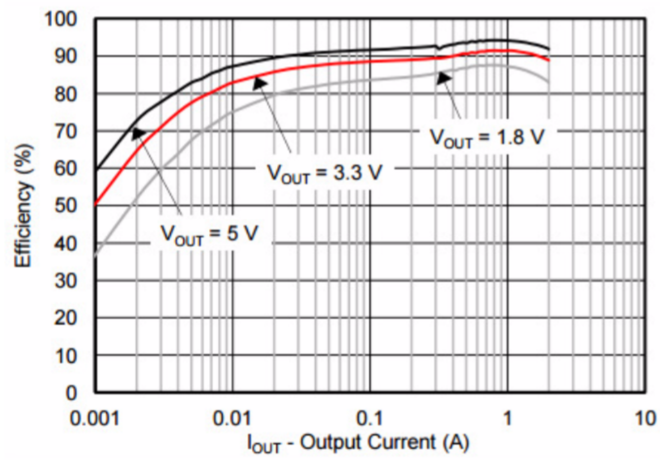

Figure 18: TPS 562200 Efficiency Curve

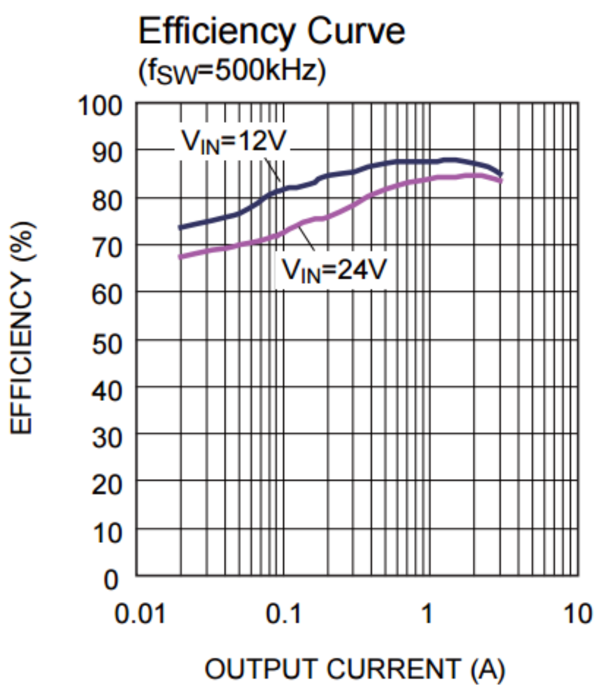

Figure 19: MP1584 Efficiency Curve

6.1.2 Charge Controller Design Details

Power output from a solar panel varies throughout the day. Variables such as cloud coverage, geographical location, temperature levels, and orientation can all affect the output of a solar panel's electricity generation. With these inconsistent power ranges, a battery, which requires specific voltage and current ranges, needs a charge controller to control the output power of the solar panel. In this design, the charge controller circuit and components function in a way which is designed for the 12-Volt battery used in the system/composting machine. This is important since the charge controller will ensure that the battery used maintains a healthy status and is kept in good operating condition. While the battery is charged, the charge controller will reduce current to ensure the battery is in a steady and stable condition. When the battery has a lesser charge, the charge controller will know to increase the current and quicken the charge time needed to bring the battery back to full capacity. The charge controller design implements its own custom algorithm that is used to implement this logic. Temperature of the battery is also a characteristic that needs to be considered as with varying temperature, optimal charging conditions change. This circuit includes a temperature sensing design which monitors the battery's current operating temperature. As long as it is operating within certain ranges, the charge controller will ensure the proper current is maintained. The key parameters that the charge controller pays attention to are the solar panel voltage and the battery voltage. From the comparison of these two values, the correct charging mode can be determined. When the voltage from the panel is less than the battery voltage, no charging will take place. When the solar panel output voltage is greater than the battery voltage the algorithm will then compare the battery voltage to the three thresholds (Bulk, Absorption, Float) and determine the amount of current to pass from the panel to the battery. Bulk is then the battery is the lowest and can be charged safely with a high current. Absorption is during the final 20% of charging where current should be limited to maintain good battery health. Finally, float charge is minimal current applied to keep the battery at full capacity and isn't overcharged. In Figure 20 it is shown how the entire charge controller is designed.

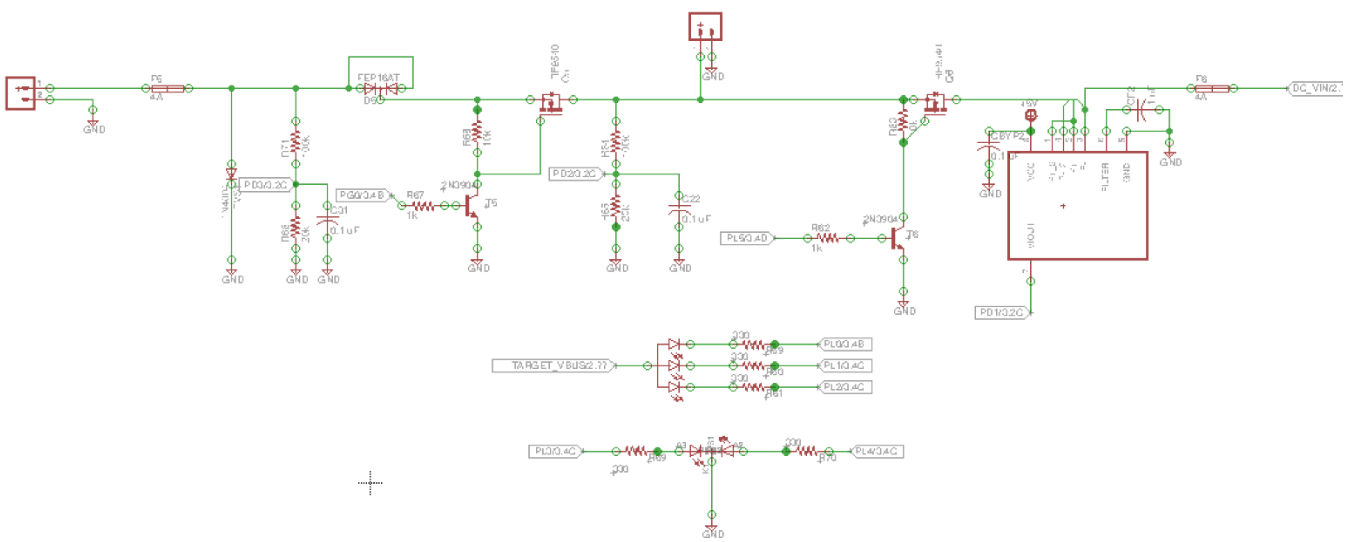

Figure 20: Charge Controller Schematic

6.1.3 Battery Design Details

The battery used for this system is a 12-Volt 18 Amp Hour sealed lead acid battery. The voltage is important as the entire DC-DC conversion design is based off of this voltage level. Additionally, the charge controller design was specifically implemented for a 12-Volt battery. This battery is the key to the entire system enabling operation of all components at any desired time. Only during specific and inconsistent periods will each load require power, however, to ensure reliability, a larger capacity battery selected.

Amp Hours are a key design detail to keep in mind when selecting a battery. This system under full load requires 3.37 Amps. Since the battery chosen can provide 18 Amp hours, that means that this specific battery can provide 18 Amps at 12-Volts for one hour. To ensure something is powered for two hours, the battery will only be able to supply 9 Amps during each of the hours. The equation is the amount of Amps needed to be supplied multiplied by the desired number hours equals the number of Amp hours the battery is rated for. In Equation 1, it is shown how to arrive at the missing value if given two of load current, number of hours needed to run, and the Amp hour rating on the battery being utilized.

$$[Amps\ Needed\ for\ Load\ to\ Operate] * [\#of\ Hours\ Needed\ to\ Run\ for] = [Amp\ Hour\ Rating\ on\ Battery]$$

Equation 1: Amp Hour Rating on Battery

For the purposes of this system and to suit design requirements and specifications, the battery will be able to supply 3.6 A for 5 hours (3.6*5 = 18). With the ability to supply 5 hours of continuous power to a full on system will enable this system to be dependable and reliable when being pushed to its limits. During charging purposes, the battery does have a voltage range of 13.6-14.9. This will enable the charge controller to suitably recharge the battery under safe operating conditions.

6.1.4 Solar Panel Design Details

The importance of a solar panel in this system cannot be underrepresented. This entire system is meant to be placed outside in the elements and subject to wind, rain, and without access to electricity. The battery being utilized may be initially charged but after being depended upon by the 19 loads at various times, its charge will need to be rejuvenated. The solar panel utilized is a 50W, 12-Volt Monocrystalline solar panel. With the efficiency mentioned in section 3.3.1.1 it will recharge the battery in the least amount of time which is vital when the system is demanding power each and every day. As per the charge controller design details, the solar panel being utilized must not exceed an open circuit voltage of 25 Volts, and must not be below 15 Volts. This specific panel has an open circuit voltage of 22.7 Volts, well within that range. The output current of the panel must not be greater than 10 Amps. The panel would provide at most 4.16 Amps if the amount of energy being produced from the sun is at its maximum and the charge controller is maximizing the input current at 12 Volts [(4.16 Amps * 12 Volts) = 50W]. With an optimal output current of 2.7 Amps from the solar panel, the battery would be able to recharge at rate 80% during full load. This is an important factor as it will help in keeping the battery at a higher percentage of charge during the day to carry over into the evening and will allow the battery to last several years while not being prematurely degraded. The overall power system's parts list is shown in table 19.

Item	Name	Manufacturer	Part #	Qty	Cost ($)	Total
1	50W 12V Solar Panel	Renogy	RNG-50D-FBA	1	$89.99	**$89.99**
2	0805	AVX	08053C104KAT2A	3	$0.01	**$0.03**
3	SOD-123	Diodes Inc.	1N5819HW-7-F	1	$0.08	**$0.08**
4	0805	Kemet	C0805C100K5GACTU	1	$0.01	**$0.01**
5	1206	TDK	C3216X5R1E476M160AC	1	$0.35	**$0.35**
6	0805	Yageo America	CC0805KRX7R9BB271	1	$0.01	**$0.01**
7	0805	Yageo America	CC0805KRX7R9BB272	1	$0.01	**$0.01**
8	0402	Vishay-Dale	CRCW0402100KFKED	1	$0.01	**$0.01**
9	0402	Vishay-Dale	CRCW040210K0FKED	3	$0.01	**$0.03**
10	0402	Vishay-Dale	CRCW040210K2FKED	1	$0.01	**$0.01**
11	0402	Vishay-Dale	CRCW040210K5FKED	1	$0.01	**$0.01**
12	0402	Vishay-Dale	CRCW040213K0FKED	1	$0.01	**$0.01**
13	0402	Vishay-Dale	CRCW0402158KFKED	1	$0.01	**$0.01**
14	0402	Vishay-Dale	CRCW04021M33FKED	1	$0.01	**$0.01**
15	0402	Vishay-Dale	CRCW040233K2FKED	1	$0.01	**$0.01**
16	0402	Vishay-Dale	CRCW0402383KFKED	1	$0.01	**$0.01**
17	0402	Vishay-Dale	CRCW040256K2FKED	1	$0.01	**$0.01**
18	0402	Vishay-Dale	CRCW040268K1FKED	1	$0.01	**$0.01**
19	0402	Vishay-Dale	CRCW0402732RFKED	1	$0.01	**$0.01**
20	0402	Vishay-Dale	CRCW040284K5FKED	1	$0.01	**$0.01**
21	0201	MuRata	GRM033R61A822KA01D	1	$0.01	**$0.01**
22	0402	MuRata	GRM155R61A104KA01D	1	$0.01	**$0.01**
23	0603	MuRata	GRM188R60J106ME47D	1	$0.02	**$0.02**
24	0603	MuRata	GRM188R60J475KE19D	1	$0.01	**$0.01**
25	0603	MuRata	GRM188R61C225KE15D	1	$0.02	**$0.02**
26	0805	MuRata	GRM21BR60J226ME39L	1	$0.04	**$0.04**
27	0805	MuRata	GRM21BR61E475MA12L	1	$0.02	**$0.02**
28	1206_190	MuRata	GRM31CR61A226KE19L	3	$0.07	**$0.21**
29	1206_190	MuRata	GRM31CR71E106KA12L	2	$0.05	**$0.10**
30	1210	MuRata	GRM32ER61E226KE15L	3	$0.16	**$0.48**
31	1210_280	MuRata	GRM32ER7YA106KA12 L	1	$0.22	**$0.22**
32	MF05A	Texas Instruments	LM3674MFX-1.2/NOPB	1	$0.32	**$0.32**
33	NLCV32	TDK	NLCV32T-220K-PF	1	$0.10	**$0.10**
34	NLCV32	TDK	NLCV32T-2R2M-PFR	1	$0.10	**$0.10**
35	SOD-323	Diodes Inc.	SD103BWS-7-F	1	$0.08	**$0.08**
36	SDR0503	Bourns	SDR0503-100ML	1	$0.19	**$0.19**
37	SRN6045	Bourns	SRN6045-4R7Y	2	$0.16	**$0.32**
38	SRN8040	Bourns	SRN8040-2R2Y	1	$0.22	**$0.22**
39	DDA0008H	Texas Instruments	TPS54332DDAR	1	$0.73	**$0.73**
40	DDC0006A	Texas Instruments	TPS562200DDCR	2	$0.47	**$0.94**
41	DDC0006A	Texas Instruments	TPS563200DDCR	1	$0.52	**$0.52**
42	S-PWSON-N6	Texas Instruments	TPS61170DRVR	1	$1.00	**$1.00**
43	R-PWSON-N10	Texas Instruments	TPS62175DQCR	1	$0.60	**$0.60**

Item	Name	Manufacturer	Part #	Qty	Cost ($)	Total
44	XAL4030	Coilcraft	XAL4030-332MEB	1	$0.72	**$0.72**
45	12V 18Ah Lead Acid	Universal Power Group	UB12180MP2180	1	$37.49	**$37.49**
46	P-MOSFET	Infineon Technologies Americas Corp.	IRF9540NSTRLPBF	2	$1.89	**$3.78**
47	POWER DIODE (10A)	Vishay Semiconductor Diodes Division	MBR2045CT-E3/45	1	$1.58	**$1.58**
48	POWER DIODE (2A)	Vishay Semiconductor Diodes Division	VESD12-02V-G-08	1	$0.38	**$0.38**
49	VOLTAGE REGULATOR	Fairchild Semiconductor	LM7805CT	1	$0.62	**$0.62**
50	TEMPERATURE SENSOR	Texas Instruments	LM35DMX/NOPB	1	$2.21	**$2.21**
51	CURRENT SENSOR	Allegro MicroSystems, LLC	ACS712ELCTR-05B-T	1	$4.82	**$4.82**
52	TVS DIODE	Littelfuse Inc.	P6KE36CA	1	$0.49	**$0.49**
53	TRANSISTOR	Fairchild Semiconductor	2N3904BU	1	$0.18	**$0.18**
54	100K RESISTOR	Yageo	RC0603JR-07100KL	2	$0.10	**$0.20**
55	20K RESISTOR	Yageo	RC0603FR-0720KL	2	$0.10	**$0.20**
56	10K RESISTOR	Yageo	RC0402JR-0710KL	2	$0.10	**$0.20**
57	1K RESISTOR	Yageo	RC0402JR-071KL	2	$0.10	**$0.20**
58	330 OHM RESISTOR	Yageo	RC1206FR-07330RL	5	$0.10	**$0.50**
59	0.1 uF CERAMIC CAPACITOR	Murata Electronics North America	GRM155R71C104KA88J	2	$0.10	**$0.20**
60	100 uF CERAMIC CAPACITOR	Murata Electronics North America	GRM31CD80J107ME39L	1	$0.55	**$0.55**
61	10uF CERAMIC CAPACITOR	Murata Electronics North America	GRM155R60G106ME44D	1	$0.12	**$0.12**
62	RGB LED	Cree Inc.	XMLCTW-A0-0000-00C3AAAA1	1	$13.73	**$13.73**
63	BI COLOR LED	Dialight	5513007F	1	$1.77	**$1.77**
64	6 PIN HEADER	Harwin Inc.	M20-9980346	2	$0.17	**$0.34**
65	HEAT SINK	avid Thermalloy	507302B00000G	3	$0.21	**$0.63**
66	FUSE HOLDER	Littelfuse Inc.	0154010.DR	2	$2.60	**$5.20**
67	10 AMP FUSES	Littelfuse Inc.	0451010.MRL	2	$1.84	**$3.68**
68	Pole Mount	Universal Solar	HD/UPM	1	$58.99	**$58.99**
Total						**$235.67**

Table 19: Power System Bill of Materials

6.2 Microcontroller

After careful review of the potential microcontroller candidates for the composting system, the one that fits best with the requirements and needs of the project is the TM4C129x. This series of microcontrollers comes uniquely with integrated Ethernet MAC + PHY for better connectivity to the cloud and the Internet of Things (IoT), as well as an on-board Liquid Crystal Display (LCD) controller which helps to save board space. However, due to the fact that it is much easier and simpler to work with an external Wi-Fi Adapter, and that the final product will be a miniature version, the composting system will not be making use of the integrated Ethernet MAC + PHY since there would be no need for such connectivity. Though it serves as a good feature to have when the system will be scaled up. As for the LCD controller, the 129DNCPDT does not have that specific feature as it is only available in other 129x microcontrollers that use a Ball Grid Array (BGA) packaging. This explains why the 129DNCPDT was chosen as it uses Quad-Flat Packaging, which is much easier and less time-consuming to solder ICs onto than the BGA packaging. Therefore, a separate controller will be used in order to allow the microcontroller to communicate with the LCD.

6.2.1 Performance

The 129DNCPDT is equipped with the ARM Cortex-M4F processor core that is capable of operating at 120 MHz. The Cortex-M family of processors includes an integrated sleep mode and state retention capabilities that allows for high performance with low-power consumption. This is beneficial to the composting system as there will be long periods of time during the composting process where little attention is needed for the composting pile, thus, there would be no need for full-power capabilities. The Cortex-M4 has a variety of highly efficient signal processing features for digital signal control that puts it over the previous generations. The processor also has a single precision Floating Point Unit (FPU) which would greatly help in more accurately dealing with the data input from the composting system.

In terms of memory, the 129x offered the most memory storage out the three potential choices (MSP430, TM4C123x, and TM4C129x), with the 129DNCPDT providing a good 1 MB of flash memory, 256 KB of SRAM, and 6 KB of EEPROM. It also has an External Peripheral Interface (EPI) that is used to communicate and connect to not only peripherals, but also to external memory. EPI acts like a high-speed bus and supports contiguous memory access independent of data bus width, allowing for direct code execution from memory.

For analog support, the 129DNCPDT comes with three integrated analog comparators, which are used for applications within the composting system that require comparisons between two signals such as the battery charger, ADC, sensors, etc. The microcontroller also provides its own converters, two 12-bit ADC modules, each with a maximum sample rate of one million samples/second. While the 129DNCPDT does not have a Digital-to-Analog Converter (DAC), it does come with a generous number of digital comparators (16 of them in total, eight for each of the ADC module) that are used to compare binary signals coming out of the ADC.

The 129DNCPDT ADC gathers sample data by using a programmable sequence-based method instead of the traditional single or double-sampling methods seen on other ADC modules. Each sample sequence is a fully programmed series of continuous samples, enabling the ADC to accumulate data from multiple input sources without having the need to be re-configured by the processor. The sampling control and data capture is controlled by the sample sequencers, which are all identical in performance except for the number of samples that can be captured and the depth of the FIFO (First In First Out) Buffer. For a given sample sequence, each sample is determined by bit fields in the ADCSSMUXn (ADC Sample Sequence Input Multiplexer Select), ADCSSEMUXn (Extended Multiplexer Select), and ADCSSCTLn (Sample Sequence Control) registers. The sample sequencers are enabled by setting the respective ASENn bit in the ADCACTSS (Active Sample Sequencer) register. Sampling is then started by setting the SSn bit in the ADCPSSI (Processor Sample Sequence Initiate) register. This is the default trigger. Other ways that sampling can be triggered is through the analog comparators, an external signal on a GPIO, a GP timer, a PWM generator, and continuous sampling. After a sample sequence is completed, the resulting data can be stored and later obtained from the ADCSSFIFOn (Result FIFO) registers or sent to the digital comparators. The data then are compared against the user programmable limits that can be set in the ADCDCCMPn (Digital Comparator Range) registers.

For increased number of connections to external peripherals, the 129DNCPDT provides a GPIO (General-Purpose Input/Output) module that consists of 15 physical GPIO blocks, each corresponding to an individual GPIO port. The GPIO module supports up to 98 programmable input/output pins, depending on configuration. Some of these pins can function as I/O signals for the on-chip peripheral modules. The GPIODIR (GPIO Direction) register, located in the Data Control block, is what configures the individual pin as either input or output. When the bit is cleared, the pin is configured as an input, and the corresponding data register bit retrieves and stores the value on the GPIO port. When the bit is set, the pin is configured as an output and the data in the GPIODATA register is moved out of the port. Having a large number of GPIO pins means there can be more connection to external peripherals without the concern of having a set amount of input and output pins.

6.2.2 Communication Interfaces & Peripherals

The 129DNCPDT offers a large amount of different communication interfaces, much more than the other two microcontroller candidates, that can be utilized to communicate with various external peripherals. It comes with eight UART (Universal Asynchronous Receiver/Transmitter) modules used for simple asynchronous communication. Each module performs conversion of parallel-to-serial and serial-to-parallel. The module can transmit and/or receive TXE and RXE bits of the UARTCTL (UART Control) register. The transmit logic performs parallel-to-serial conversion on the data taken from the transmit FIFO. The control logic outputs the serial bit stream starting with a start bit, followed by the data bits (Least Significant Bit first), parity bit, and the stop bits. On the other hand, the receive logic performs serial-to-parallel conversion on the received bit stream after detecting a valid start pulse. The data is then stored in the receive FIFO. The UART protocol is less complex and is easier to work with and since it only requires two pins in total to transfer data, one for transmitting and one for receiving, it is generally preferred over other interfaces. Also, the UART modules on the 129DNCPDT allow for data rate transfer of up to 15 Mbps in high speed mode (divided by 8) and 7.5 Mbps in regular speed mode (divided by 16). The only drawback to the UART protocol is its asynchronous property. If both sides do not use the same clocks, it can affect the speed and timing of the transmission.

Another type of communication interface that the 129DNCPDT has is the I^{2}C (Inter-Integrated Circuit) protocol. The microcontroller provides up to ten modules with four different transmission speeds, including a high-speed mode. The I^{2}C protocol is a popular interface that is generally used to connect and communicate with devices such as sensors, LCDs, networking devices, and so on. The interface can also be used for system testing and diagnostic purposes. The most important aspect of the I^{2}C protocol is that it allows for both a single master and multiple master devices to communicate with and control single and multiple slave devices. This, combined with the extremely low required pin count of only two for any number of peripherals, makes the I^{2}C protocol ideal for connecting with multiple devices since it helps reduce cost and complexity of the circuit as more devices are added to the system, even if it is slower compared to other interfaces. Each I^{2}C module consists of both master and slave functions each having a unique address. A master-initiated communication generates the clock signal, SCL. For proper performance, the SDA pin must be configured as an open-drain signal while the SCL pin must not be configured as one. Both signals must also be attached to a positive supply voltage through the use of pull-up resistors, as seen in Figure 21.

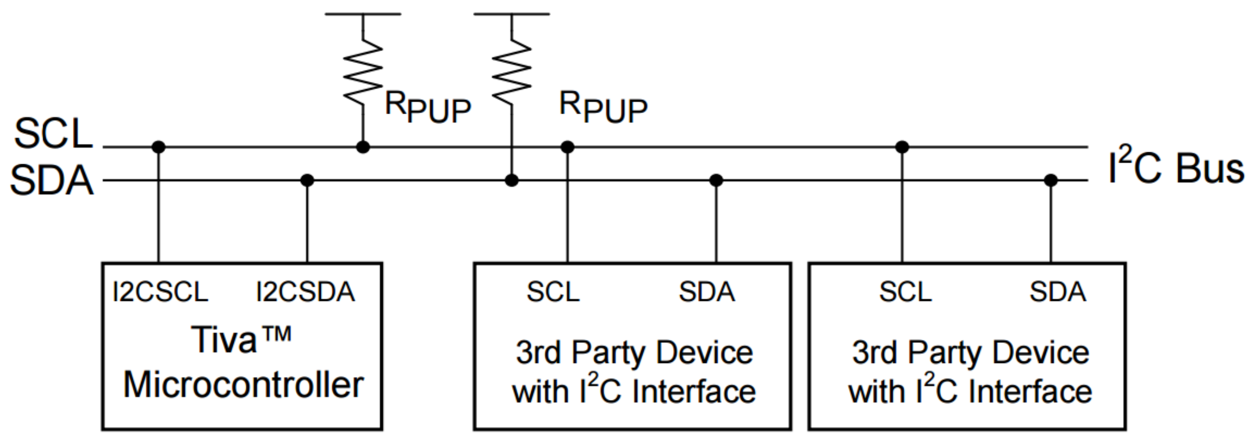

Figure 21: Standard I2C Bus (Courtesy of Texas Instruments)

The two signals that the I^{2}C module on the 129DNCPDT uses, SDA and SCL, are named I2CSDA and I2CSCL. Both are bi-directional, but one is only for data and the other is a clock for synchronization. The bus is idle when both signals are high. Every transaction is nine bits long with eight bits of data and one acknowledge bit and can be transferred continuously as long as each byte is separated by an acknowledge bit. Also, the data must be transferred with the MSB first. The I^{2}C protocol defines two states for the beginning and ending of a transaction: START and STOP. The STOP bit determines if the cycle stops at the end of a transfer or keeps going on to another transfer with a repeated START condition. To produce a single cycle, the I2CMSA (Master Slave Address) register needs to be provided with the desired address, the R/S (message direction) bit cleared, and the Control register configured to perform the operation and stop. When the operation is done or aborted, the interrupt pin is enabled and the data can be read from the I2CMDR (Master Data) register.

When the I^2C module is in Master receiver mode, the acknowledge bit is transmitted automatically after each byte. The ACK bit needs to be cleared when the master does not require any more data from the slave. When in slave mode, the STARTRIS and STOPRIS bits in the I2CSRIS (Slave Raw Interrupt Status) register specifies the start and stop conditions on the bus and the I2CSMIS (Slave Masked Interrupt Status) register can be set to allow these two bits to become the controller interrupts. Both the master and the slave module have the ability to access two 8-byte FIFOs that can be used with the μDMA for fast data transfer. Both of the transmit (TX) FIFO and the receive (RX) FIFO can be separately assigned to either the master or the slave. Therefore, both FIFOs can either be assigned to the master, both to the slave, or one can be assigned to the master while the other assigned to the slave and vice versa. This assignment can be set by configuring the TXASGNMT and RXASGNMT bit in the I2CFIFOCTL (FIFO Control) register.

The sensors that are to be used within the composting system are the SEN0193 soil moisture sensor and the Parallax IR Transmitter/Receiver (distance sensor), which are analog output sensors, and the DS18B20 temperature sensor, which is a digital output sensor. The 129DNCPDT microcontroller has altogether a total of 128 pins, each can be configured to have a different functionality. Some pins can only have one single functionality, while others have multiple functionalities that users can choose from to configure the pin. This difference can be seen in Table 20. Thus, to read in data from the output voltage of the analog sensors, the output pin on the sensors must be connected to the pin that has the capability to be configured as an ADC input. For example, the data output pin for the SEN0193 could be connected to pin 128 after it has been configured to be an ADC input pin.

Pin Number	Pin Name	Pin Type	Buffer Type	Description
113	VDD	-	Power	Positive supply for I/O and some logic.
128	PD7	I/O	TTL	GPIO port D bit 7.
	AIN4	I	Analog	Analog-to-digital converter input 4.
	NMI	I	TTL	Non-maskable interrupt.
	SSI2XDAT2	I/O	TTL	SSI Module 2 Bi-directional Data Pin 2.
	T4CCP1	I/O	TTL	16/32-Bit Timer 4 Capture/Compare/PWM 1.
	U2CTS	I	TTL	UART module 2 Clear To Send modem flow control input signal.
	USB0PLT	I	TTL	Optionally used in Host mode by an external power source to indicate an error state by that power source.

Table 20: Comparison of Functionalities Between 2 GPIO Pins.

For the DS18B20 temperature sensor, since it outputs a digital signal and uses a 1-wire interface, there is no need to connect it through an ADC. The UART interface can be configured to communicate with the 1-wire interface. 1-wire devices operate in an open-drain environment on bus voltages between 2.0 to 5.5 V, depending on the device. A 4.7 kOhm resistor is usually used as the pullup resistor on the 1-wire data line. This is similar to the I^2C protocol in the sense that both use pullup resistors and function in an open-drain environment, but since I^2C uses two signals instead of one, it cannot interface with a 1-wire device without the use of an I^2C to 1-wire bridge device. Thus, the UART interface will be used to communicate with the DS18B20 temperature sensor. Figure 22 shows a general circuit of how the two interfaces interact with each other. Also, since most UART transmit data pins are not open drain, an external open-drain buffer circuit is usually required for the two interfaces to properly communicate with each other. Figure 23 and 24 show two different ways the buffer can be designed.

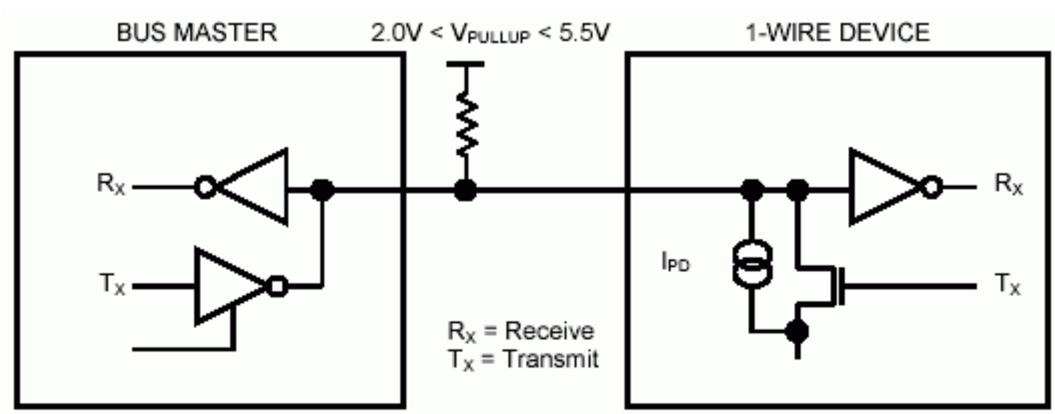

Figure 22: 1-Wire Bus Interface (Copyright Maxim Integrated Products (http://www.maximintegrated.com). Used by permission.)

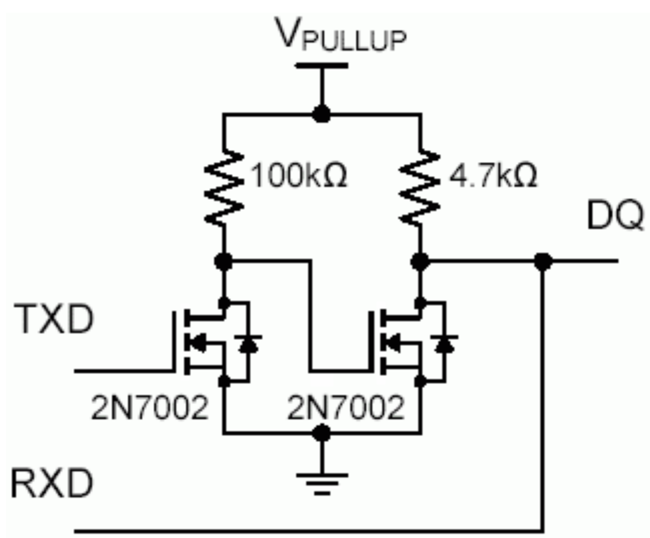

Figure 23: Discrete Open-Drain Circuit (Copyright Maxim Integrated Products (http://www.maximintegrated.com). Used by permission)

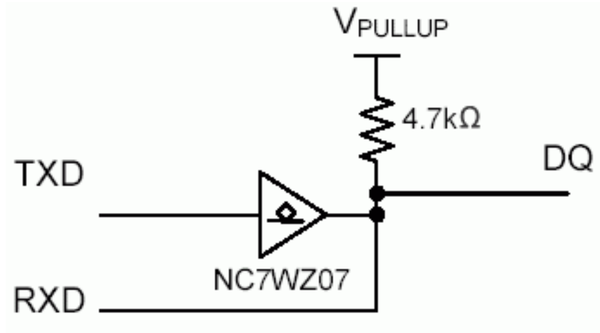

Figure 24: Integrated Open-Drain Circuit (Copyright Maxim Integrated Products (http://www.maximintegrated.com). Used by permission)

Another peripheral that will be making use of the UART module on the microcontroller is the Wi-Fi Controller. A 5-wire interface shall be used between the microcontroller and Wi-Fi Controller as this allows the best reliability and flexibility for communication. Besides the two data signals TX and RX, the 5-wire interface also includes two flow control signals, Request To Send (RTS) and Clear To Send (CTS), and an interrupt signal. All UART modules on the microcontroller provide the data and flow control signals and a GPIO pin can be set aside specifically for receiving the interrupt signal from the Wi-Fi Controller. Figure 25 shows the connection between the microcontroller and the Wi-Fi Controller using a 5-wire UART interface.

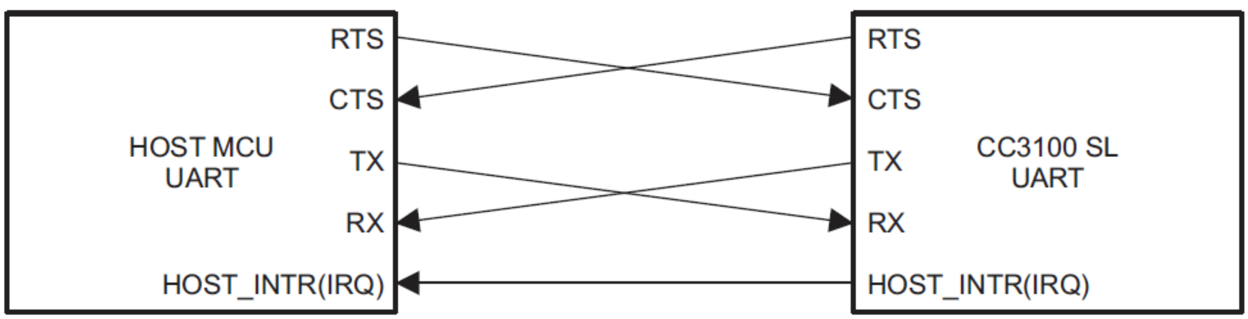

Figure 25: 5-Wire UART Interface for Wi-Fi Controller

Due to the complexity of this Wi-Fi controller and the time constraint, a decision was made to scrap and replace this controller with another simpler one: the ESP8266 Wi-Fi Controller, which will be discussed with more details in section 6.3.2.2. This controller also uses UART, but instead of requiring five communication lines with the MCU like with the CC3100, it only requires two: the transmit (TX) and receive (RX) signal.

For user interface, the display that the composting system will the using requires the microcontroller to communicate with it via an LCD controller and a touch panel controller. The LCD controller consists of 128 pins in total, of which up to 30 pins are required to interface with the microcontroller. The TTL clock input pin will not be used and therefore be connected to ground. Instead, a crystal oscillator will be used as the reference clock. Up to 24 of the GPIO pins on the microcontroller are needed to connect to the 24-pin data bus on the LCD controller. This data bus transmits/receives display information to the microcontroller, and can be formatted to be either 8-bit, 9-bit, 16-bit, 18-bit, or 24-bit. Any pins that are not used can be left as floating pins.

Of the seven remaining pins on the LCD Controller, six are input pins that consist of one control pin and one is an output pin TE that sends feedback signal to the microcontroller regarding tearing effects. The control pin RESET# is responsible for resetting the master synchronization. The other four inputs pins consist of CS#, D/C#, E(RD#), and R/W#(WR#). Figure 26 shows the interface between the LCD Controller and the microcontroller.

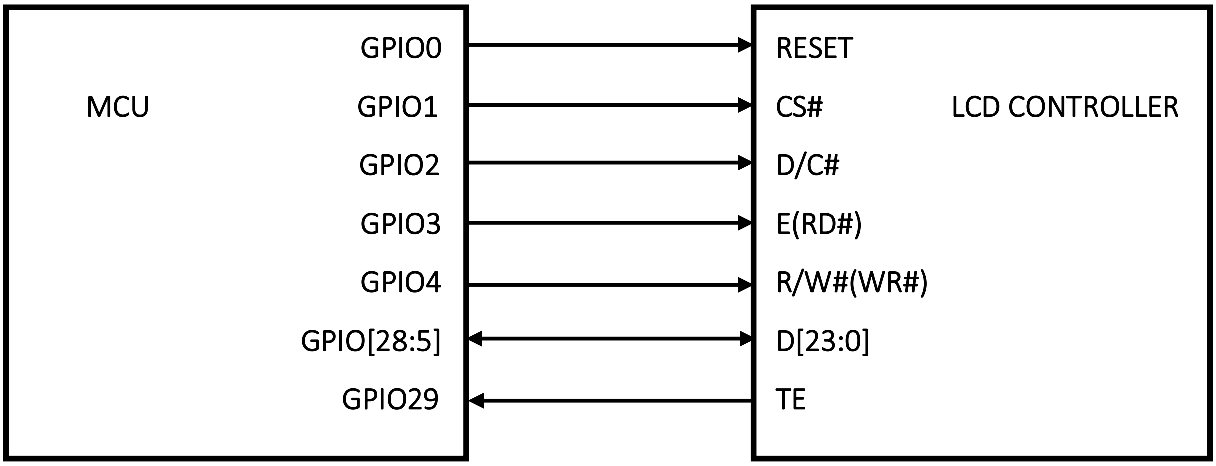

Figure 26: MCU & LCD Controller Interface

The display also comes with a touch screen controller (as a single unit) that has its own pin connections that must also be established for the microcontroller to interface with the touch screen. The interface only requires five pin connections, which consists of two I^2C interface pins for data exchange, an interrupt pin to notify the microcontroller that the data is ready to be read, another interrupt pin that allows the microcontroller to wake the touch screen controller by changing its operation mode from Hibernate to Active, and a reset pin. On the microcontroller side, one I^2C module will be used for the I^2C interface data pins as well as three GPIO pins for the interrupts and reset. Figure 27 shows the visual of the interface between the microcontroller and the touch screen controller.

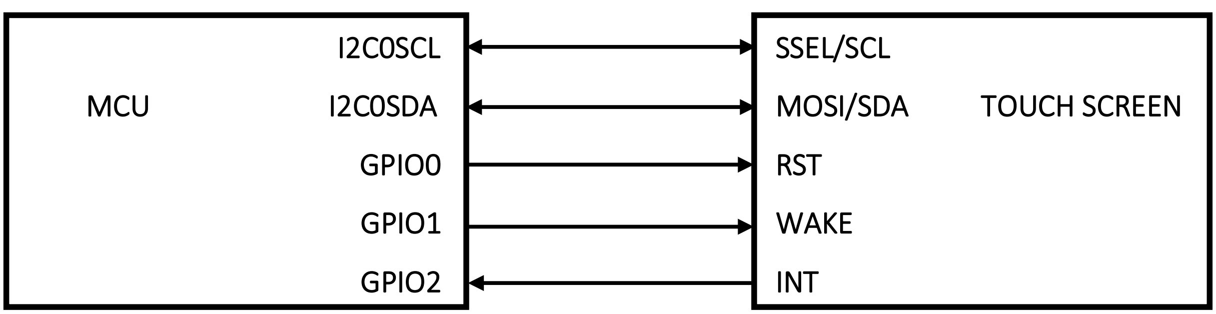

Figure 27: MCU & Touch Screen Controller Interface

This LCD and its touch screen were both also not used in the final design due to techincal difficulties. The touch screen itself works fine with the MCU, but the LCD refused to proceed past the initialization process. Months were spent exchanging emails with the LCD's company technical help line, but the problem was never resolved. However, the LCD does work with the Arduino Mega, using the codes provided on the company's website (which is made for compatibility with the Arduino Mega). Because of this, a possible explanation for why it works with Arduino but not with the ARM Tiva C MCU is because of the difference in timing, as the Tiva C MCU runs at a much higher speed than the Arduino Atmega.

The new LCD that is used as a replacement is a simple 16x2 display with 4-button inputs, and can be communicated with using the I^2C protocol. While it is simple to communicate with and easy to use, as well as satisfying the bare minmum requirements for the project, it has significant drawbacks. First, the small display size of 16x2 greatly increased the number of screens that the user has to click through, while limiting the amount of information (simple texts with no graphics) that can be shown at a time. Second, the state of the buttons can only be accessed through I^2C commands, thus not being able to generate their own interrupts. This means that every time the MCU needs to know which button was pressed, it has to send a specific command through I^2C and wait for the response, ultimately resulting in the user having to press and hold a button down until the MCU receives the response back from the LCD.

6.2.3 Control Interfaces & Peripherals

In addition to the standard communication interfaces that most microcontrollers have, the 129DNCPDT also comes with two advanced motion control interfaces. The first one is the PWM (Pulse Width Modulator). PWM is a technique used to control the power supplied to devices. High-resolution counters are used to produce a square wave, and the duty cycle of the wave is modulated to encode an analog signal. This is commonly used in motor control, which is what will be used in the composting system in order to drive the motor that is used to rotate the container that holds the compost as well as the fan. PWM can also be used to control the brightness of a light source, which will be used to control the brightness of the LCD if needed, though this is controlled by the LCD controller and not the 129DNCPDT microcontroller. The 129DNCPDT microcontroller has one PWM module that consists of four PWM generator blocks and a control block, totaling eight PWM outputs. The control block verifies the polarity of the PWM signals, which are to be passed through to the pins. Each PWM generator block generates two signals that can be programmed with either the same or independent operations. The output signals, pwmA' and pwmB', are managed by the output control block before being passed to the device pins, in pairs, starting from MnPWM0 and MnPWM1. This can be seen in Figure 28.

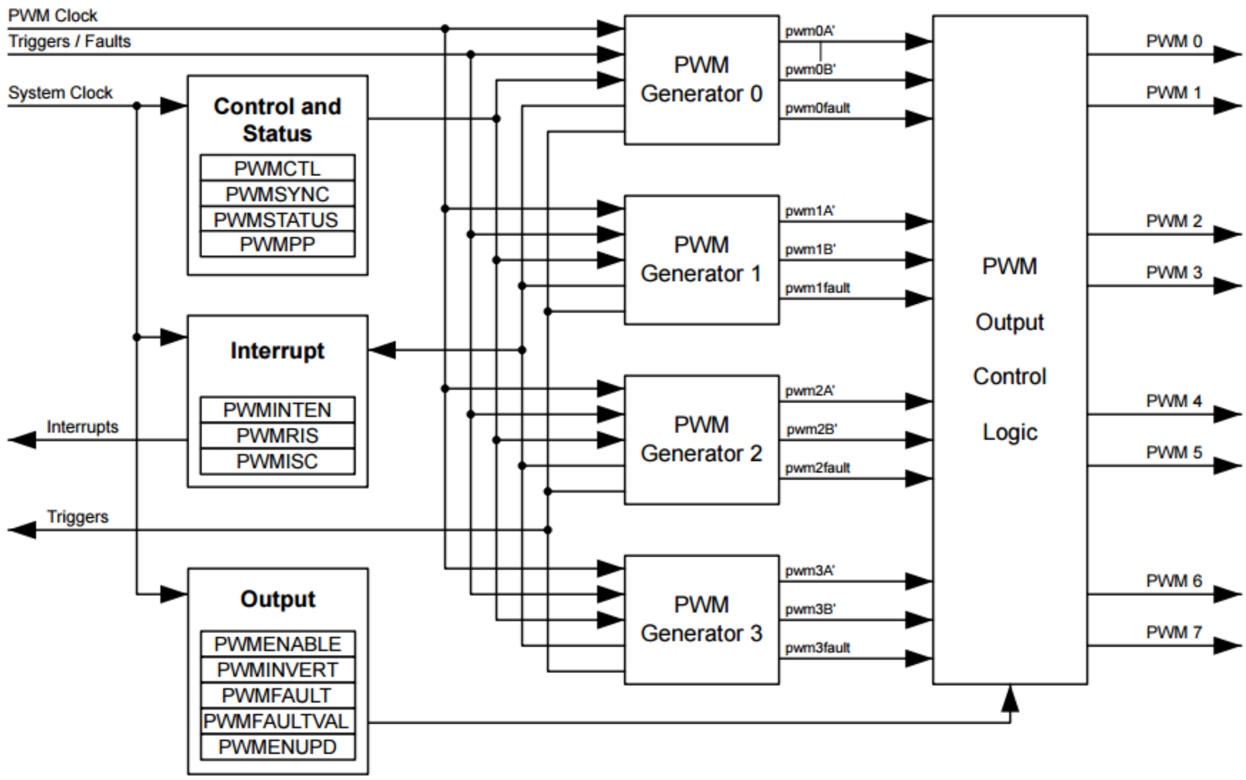

Figure 28: PWM Module (Courtesy of Texas Instruments)

The motor selected for the composting system shall be powered by the power subsystem, and controlled by the PWM module of the microcontroller. Just connecting the motor directly to the microcontroller might damage the microcontroller as common DC motors require a current amount larger than the microcontroller can supply. Thus, a motor driver circuit is needed to properly interface the motor and allows the PWM on the microcontroller to regulate the voltage. A power transistor is used as a switch to switch on or off the motor, and adjust the rotation speed depending on the voltage. This circuit is shown in Figure 29.

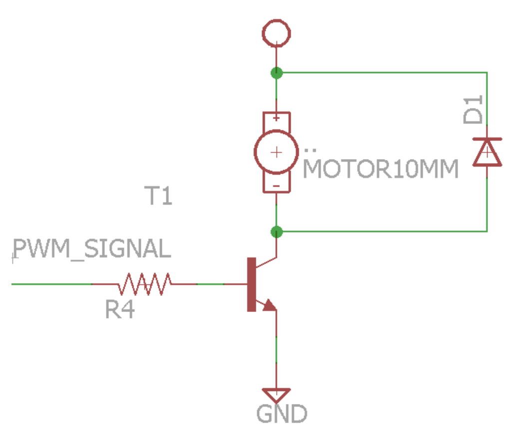

Figure 29: Motor Driver Schematic

6.2.4 Schematics & BOM

Each individual component that interfaces with the microcontroller has been discussed thus far. This section shall bring those components together in the form of schematic diagrams. These schematics show a larger view of how the entire microcontroller is designed to connect to the different components. This is seen in Figure 30 and 31, which show the circuitry between the GPIO pins and the components (sensors, motor, LCD, etc.), as well as what each individual pin is used for. It is important to note that the GPIO pins that are left floating in these two figures shall be connected to GND at the end if they are not used for anything. Figure 32 shows the pins connecting to the crystal oscillator, as well as the unused hibernation module and how the pins should be connected as this allows for better conservation of power. This also applies to the GPIO pins being connected to GND as mentioned. Lastly, Figure 33 shows the power pins connected together with decoupling capacitors to smooth out the signal. Table 21 will list these components along with their manufacturers and prices.

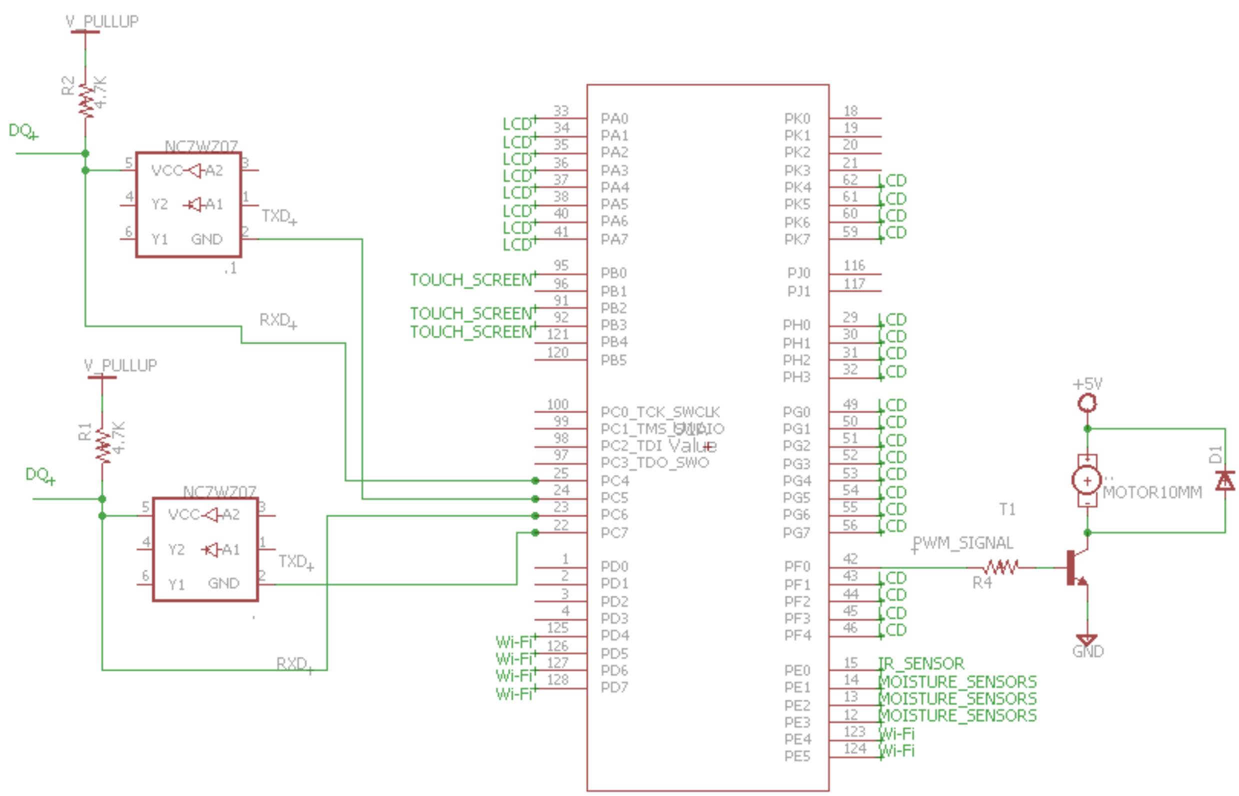

Figure 30: Microcontroller GPIO Schematic (Ports A - K)

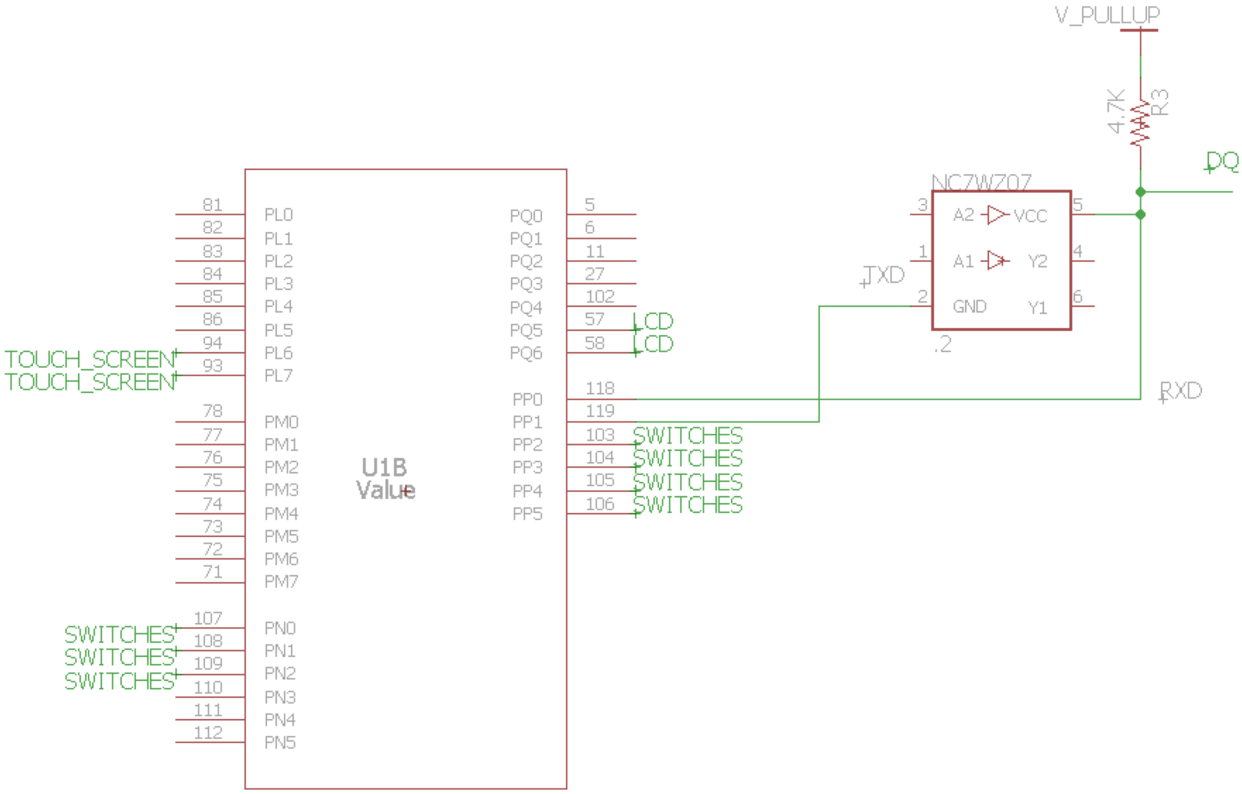

Figure 31: Microcontroller GPIO Schematic (Ports L-Q)

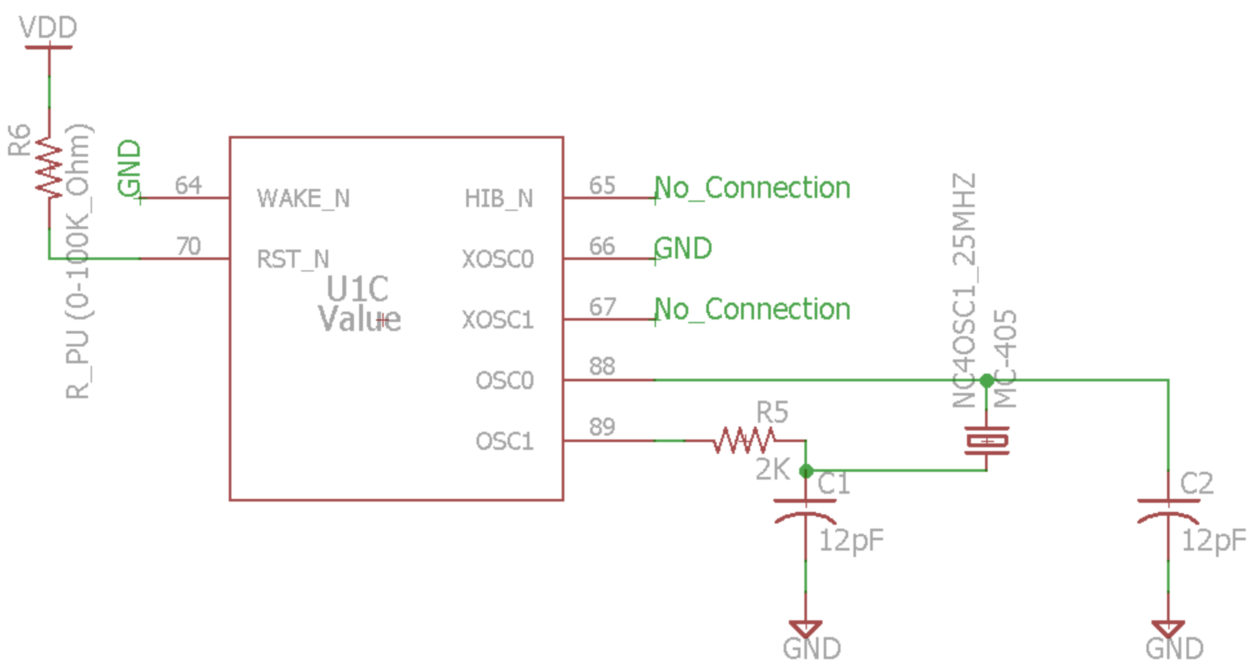

Figure 32: Microcontroller Hibernation Module Schematic

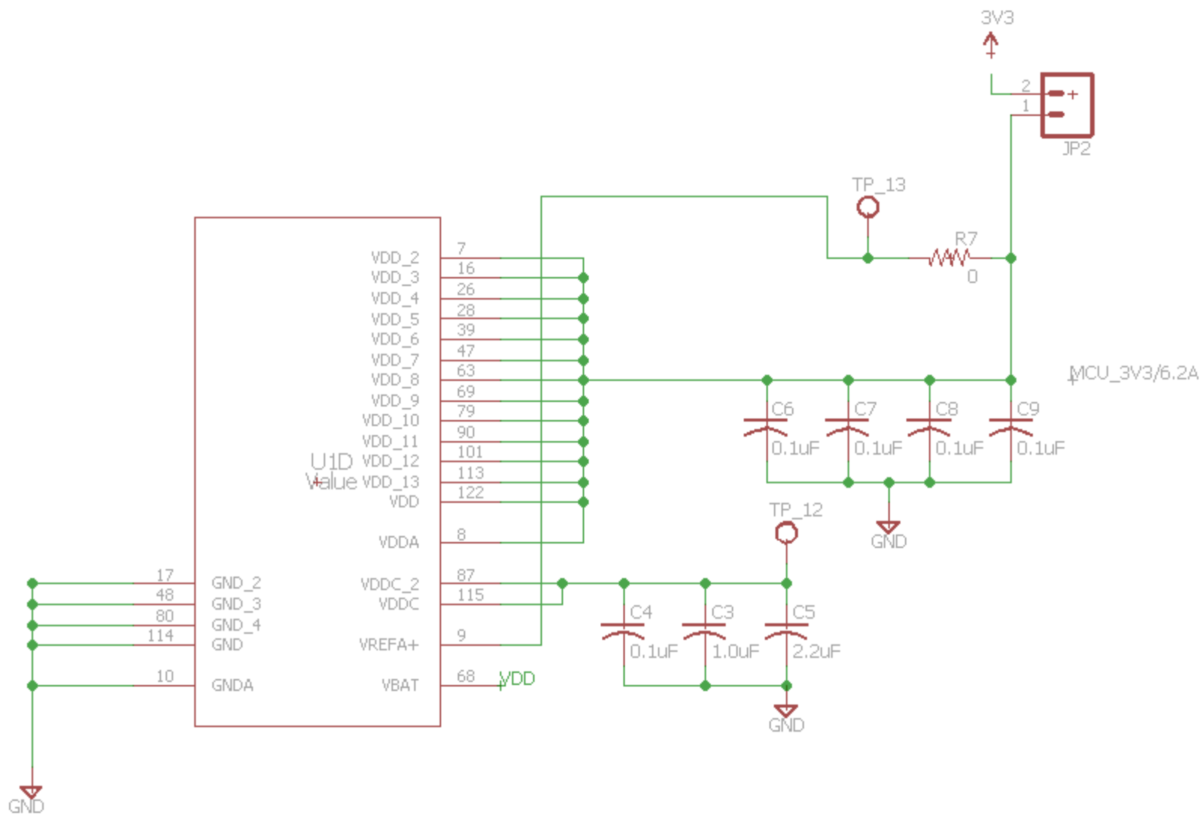

Figure 33: Microcontroller Power Schematic

Item	Name	Manufacturer	Part #	Quantity	Cost ($)	Total
1	0.1uF Capacitor	Murata Electronics North America	LLL185R71A104MA11L	5	0.24	**1.2**
2	1.0uF Capacitor	Murata Electronics North America	LLL317R71A105MA01L	1	0.34	**0.34**
3	2.2uF Capacitor	Taiyo Yuden	LWK107BJ225MV-T	1	0.47	**0.47**
4	12pF Capacitor	Murata Electronics North America	GRM1555C1H120GA01D	2	0.10	**0.20**
5	10Ω Resistor	Susumu	CPA2512Q10R0FS-T10	1	2.97	**2.97**
6	1kΩ Resistor	Yageo	RC1206FR-071KL	1	0.10	**0.10**
7	2kΩ Resistor	Stackpole Electronics Inc.	RNCP1206FTD2K00	1	0.10	**0.10**
8	4.7kΩ Resistor	Stackpole Electronics Inc.	RMCF1206FT4K70	3	0.10	**0.30**
9	NPN Transistor	Rohm Semiconductor	DTD543ZETL	1	0.39	**0.39**
10	Zener Diode	Micro Commercial Co	3SMBJ5927B-TP	1	0.44	**0.44**
11	Jumper	Harwin Inc	S1621-46R	1	0.24	**0.24**
12	Open-Drain Dual Buffer	Fairchild Semiconductor	NC7WZ07P6X	2	0.38	**0.76**
13	Crystal Oscillator	Abracon LLC	ABMM-25.000MHZ-D2X-T	1	1.00	**1.00**
14	Microcontroller	Texas Instruments	TM4C129DNCPDT	1	8.47	**8.47**
Total						**16.98**

Table 21: Microcontroller Bill of Materials

6.3 User Interface

A major aspect of the design falls within the user interface, which must be designed well since it is the connection between the user and the system. Having a good design will largely be determined by how intuitive and simple the users deem the system to be. This will be judged based on two key components: the display which is mounted on the composting machine and the mobile application which users can download to their smartphones.

6.3.1 Display

The user will interface with the automatic aerobic composting machine directly through NewHaven's 5-inch TFT LCD display NHD-5.0-800480TF-ATXL#-CTP. The main features of this display that led to this choice are the size of the screen and the displays integrated capacitive touch panel. These both allow for a very enjoyable experience with the system and will be detailed in the following two sections. However, due to technical problems when integrating this display with the Tiva-C microcontroller, the Olimex Shield LCD 16x2 was used which contains four buttons and a 16x2 7-segment display.

6.3.1.1 Size

In order to give the user a most desirable experience when interacting with the composting machine, a screen size of 5 inches along the diagonal was chosen. This allows a perfect balance between the choice of having too small of a display and the other choice of having too costly of a screen. There are many drawbacks that come with a smaller display as it gets more challenging for the design of the user interface to fit all of the necessary components onto one screen. If a smaller display is used, multiple tabs or pages of information will need to be used in order to effectively allow the user to provide accurate input especially when trying to type in information. Larger displays provide a much more immersive user experience and allow more innovation for how the UI layout can be designed. However, these displays also come with a higher price tag that would raise the cost of the composting machine. As stated, a 5-inch display will bridge the pros and cons that come with both smaller and larger displays, allowing for enough screen real-estate that the UI design can be effective for the user to engage with while also keeping the cost of the product down to an appropriate level. The chosen display features a 5-inch diagonal screen with measurements of 120.7mm x 75.8mm (L x W) allowing for 800pixels x 480pixels respectively which meets the discussed specifications.

The Olimex display comes with a significantly smaller display size and can only present 7-segment characters on two lines. This limits the amount of information that can be displayed to the user at any given time and requires a menu system to be created so that the user can select to have more information displayed to them. Four buttons on the display shield allows the user to navigate through the menu in order to access all of the controls and sensor values. Although this display does introduce a disadvantage when it comes to screen size, it greatly decreases the complexity of working with a larger display as mentioned previously since a display driver does not have to be created.

6.3.1.2 Capacitive Touch

The selected display also features a capacitive touchscreen which was deemed more appropriate for the purposes of indoor modeling and exemplification of the compost machine's design and features. Reasons for this decision are as follows: the best display should be chosen so that those who are interacting with our machine will get the best experience for the environment in which they are using the machine. Since our product will be demonstrated indoors and be used by people with simply just their fingers, it is best to use a capacitive touch display in order to give the user an enjoyable experience.

As discussed in section 3.3.3, the capacitive touch works best when human skin contact is expected and does not require that the user place any pressure on the screen which is generally received as a better display. This allows for more responsiveness and even multi-touch gestures. Since many different people will be testing the control system on demonstration day using just their finger, a capacitive touchscreen allows them to easily use and intuitively interact with the different controls and usage statistics.

It is important to note that for future advancements with the automatic composting machine a resistive touchscreen display may be considered since the product will mainly be used outdoors in an environment where users are more likely to be wearing protective gloves or may be using the display with less than clean hands. It should also be noted that the Olimex display that is used as the final display to interact with the user does not contain a touch screen display but instead provides four buttons as the means by which the user can provide input to the system. Although this is not the most ideal method for input, it does provide simplicity both to the user and to the designer.

6.3.1.3 Interface Controller

The chosen LCD display has myriad features and characteristics that, if operated by the MCU alone, will cause a lot of overhead and introduce an excessive amount of software to our system that may not necessarily need to be there. There are tasks such as frame buffering, line shifting, data transfer, vertical synchronization, and horizontal synchronization that all include intricate mechanisms and protocols that are more efficiently and easily implemented if an LCD interface controller is used. Otherwise, software and hardware would have to be designed in order create these protocols from scratch. From a high level view this allows the MCU to focus on system specific functions that only the MCU can take care of (these are discussed in section 6.4.1.1) and reduces the communication to the LCD to a few bytes of data where the MCU can simply give the LCD data without worrying about the specifics of how that data gets translated to produce an image on the LCD screen. It is worth noting that this method of interfacing with the LCD is being used due to the size of the display which was mentioned in section 6.3.1.1 as being 800 pixels x 480 pixels. If a simpler seven segment display was selected instead of the larger display, the MCU would be more than capable of its operations since much of the protocols that come with managing a large amount of pixels disappear.

Interface controllers can have many differences depending on the application that they are needed for. In order for the chosen LCD display to properly and efficiently communicate with the MCU and the rest of the system an interface controller is needed that can handle the displays 24-bit RGB data input as well as reduce the pins necessary to connect from the MCU. A frame buffer is also considered since the MCU and LCD could run at different frequencies or be able to handle data at different speeds. Therefore, a frame buffer is needed so that these differences in speed do not affect how the user interacts with the system and allow the interface controller to take care of information that is presented to the LCD. It is this piece of hardware that greatly reduces the load on the MCU since all it is then responsible for is simply sending information and trusting the interface controller to present the data to the LCD correctly. One final consideration is the type of protocols that can be implemented with the interface controller, which should be many or at least a few popular ones so that it can be versatile and have many uses for many different chips.

After discussing the features that the interface controller should have it was decided that the Solomon Systech SSD1963 LCD display controller would be used to support communication between the MCU and the display. This controller features 1215KB of memory for the frame buffer, a vast amount for the MCU to store data into, a TFT 24-bit serial RGB interface, providing a perfect connection to the LCD itself, and supports many different protocols. It is important to note that the display will connect to the PCB through a 40-pin connector since a ribbon cable is attached to the display's controller. This allows for simple pin connections from the interface controller to the LCD since they will all be routed through the connector. As for protocols, a parallel interface is supported of either Intel's 6800 protocol or Motorola's 8080 protocol while the general purpose pins can be configured to use a serial protocol such as I2C or SPI. Figure 34 and Figure 35 show the pin configurations that will be used while Table 22 shows all of the components and their cost that will be utilized.

This controller board was not used due to the complexity encountered when integrating with the Tiva-C microcontroller. Data was able to be transmitted to the display yet the initialization screen would be the only screen displayed. The final issue found was that the timing on the Tiva-C could not be generated accurately enough in order to interface with the pixel clock that the NewHaven display needed in order to read the input buffer accurately.

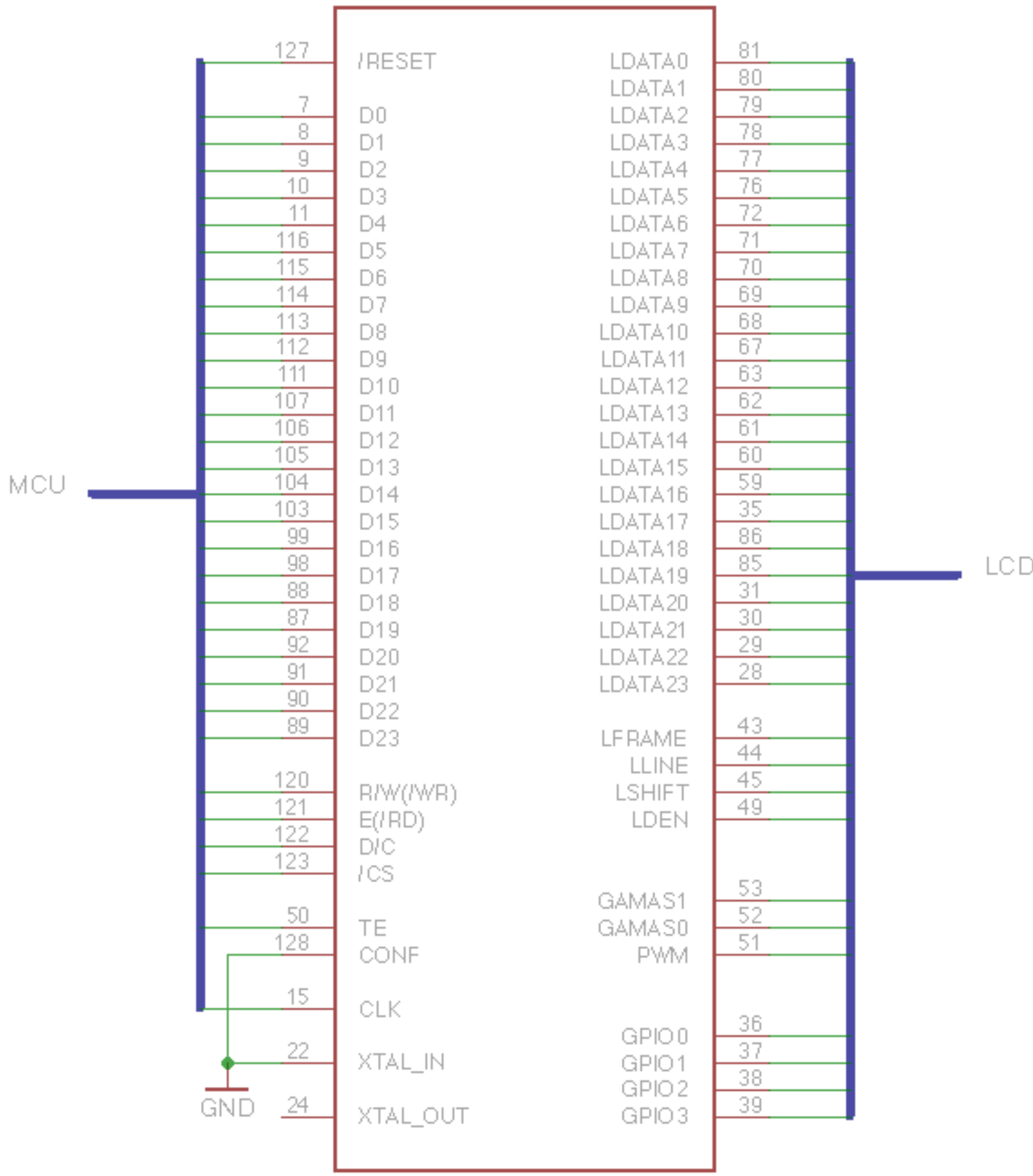

Figure 34: SSD1963 Interface Controller Schematic (Data Pins)

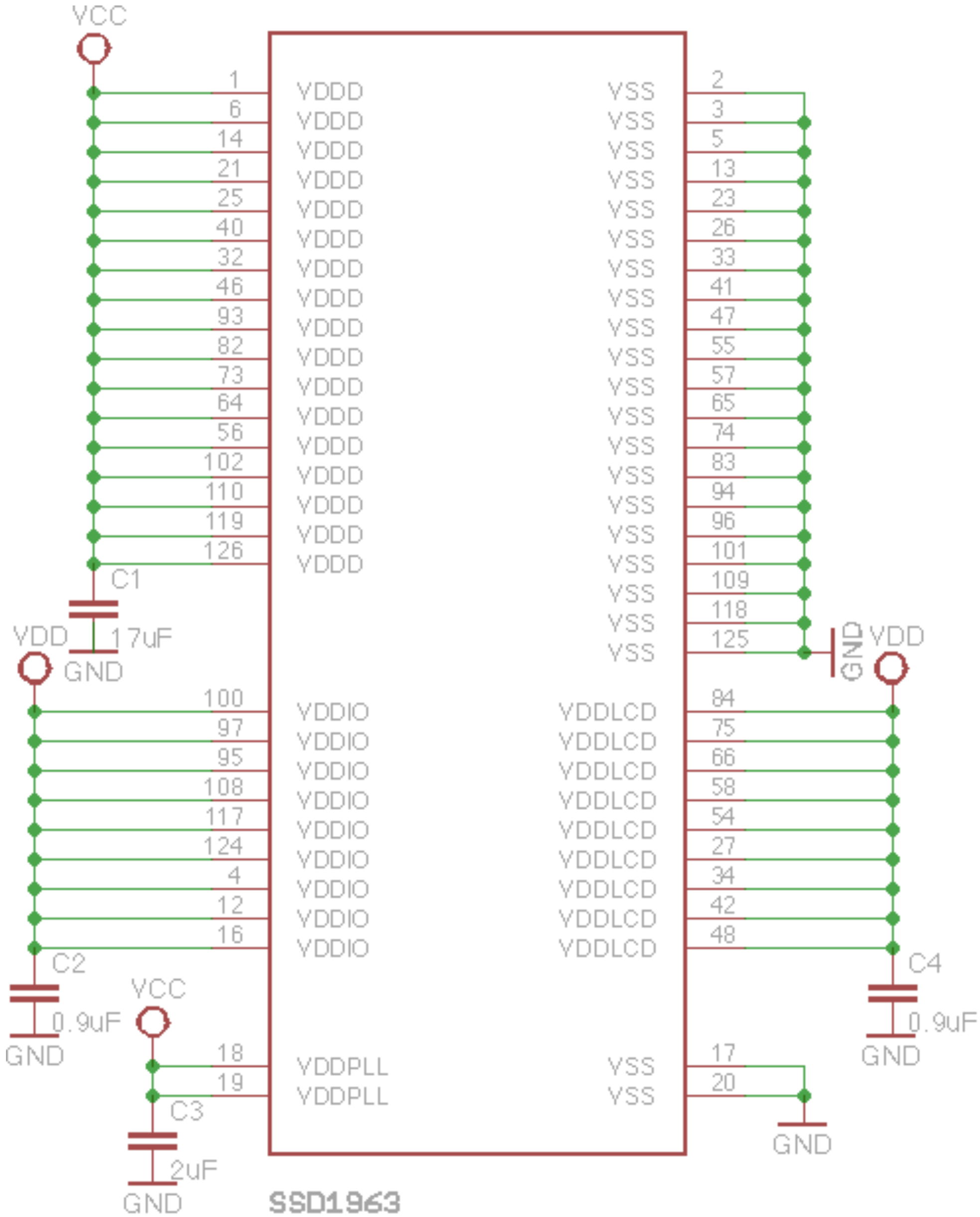

Figure 35: SSD1963 Interface Controller Schematic (Power Pins)

Item	Name	Manufacturer	Part #	Quantity	Cost ($)	Total
1	0.1uF Capacitor	Taiyo Yuden	LMK105BJ104KV-F	18	0.10	**1.80**
2	1.0uF Capacitor	Taiyo Yuden	LMK105BJ105KV-F	19	0.15	**2.85**
3	SSD1963 LCD Interface Controller	Solomon Systech	SSD1963	1	5.00	**5.00**
Total						**9.65**

Table 22: SSD1963 Interface Controller Bill of Materials

6.3.2 Mobile App

The user will be given a choice to also interface with the automatic composting machine through a mobile application which they can download to their smartphone and connect to the system through Wi-Fi. This extra form of interaction will provide features that are common to other IoT products such as communication with the system from long distances wherever an internet connection is available. With a mobile application it is believed that the user will be able to enjoy the composting machine at a much deeper level and will reinforce the idea of the machine being automatic.

6.3.2.1 iOS Development

Considering the pros and cons that were discussed in section 3.3.4, it was decided to develop the mobile application under the iOS platform to compliment the simplicity and intuitiveness that is desired with the automatic composting machine. Reasons considered include simpler UI design, better developing tools, and availability of the application to as many users as possible on launch day.

The iOS operating system is considered to be the more refined and better designed UI of the two camps. David Nield said "Overall, Apple's mobile OS adopts the more refined aesthetic, whereas Google's carries more of an impact" [15]. It is this simpler and well-designed UI that the user will get to experience through many of the features of Apple's iOS. Integration with Siri through HomeKit so that the user can directly control the composting machine with just a voice command, allowing location based notifications and reminders, and integrating iCloud synchronization between a user's multiple iOS devices are all features that make choosing iOS a supreme choice.

In view of the IDEs that were presented, iOS surely has a great advantage over Android as Xcode has been praised by many as one of the greatest design tools for creating iOS applications. Andrea Gottardo states that "the set of tools that developers are given to design their apps in iOS is the best." [16] Using Xcode provides the developer with a simple interface for coding and astounding features for laying out the user interface through drag and drop controls, storyboards that give a 40,000-foot view of the design, and easy implementation of custom APIs. Automatic layout features provide the developer with the ability to design the look and feel of their applications that dynamically calculate the size of controls, buttons, labels, and tabs based on the device that the user is interacting with. This allows the developer to design one application that can work seamlessly across multiple devices each with a different screen size and resolution.

Although writing code in Java is generally easy to understand and is more familiar across multiple developers, one of the choices with iOS is the use of Apple's inbred language: Swift. Factors driving this decision were Swift's simplicity, which allows the syntax to be learned in a matter of days instead of weeks, and Swift's security, which provides the developer with many syntactical safeguards that will reduce time spent fixing bugs that might otherwise occur in a language such as Java. With these benefits, it was determined that the mobile application can be developed on a faster timeline which compliments the shorter time limitations that this project is under.

One final consideration for the decision to use the iOS platform comes from the percentage of users running the latest software on their iOS devices. Figure 7 (in section 3.3.4.2) shows that roughly 84% of iOS device users are running iOS 9, the newest operating system which contains the latest features that Apple has to offer. This allows the mobile application to take advantage of these features and provide confidence that the vast majority of users running an iOS device will be able to take advantage of the design that is implemented. The same cannot be said for developing under the Android platform where more work and time would have to be spent designing and testing a UI that will work well on multiple operating systems and on multiple devices.

6.3.2.2 Wi-Fi Controller

Just as discussed in section 6.3.1.3 where it was mentioned that an interface controller would be required between the MCU and the LCD, such is the case here where having a mobile application presents a lot of features and complexities that the MCU simply cannot handle. One major aspect is the fact that the mobile application resides on a piece of hardware (or multiple pieces of hardware) which is separated and free from the PCB where the MCU lies. This creates the necessity for wireless communication between the mobile application and the composting machine since a hardware connection is impossible to design. In order to add wireless capabilities, a separate Wi-Fi controller must be used to allow access to the internet through which the communication with the mobile application can commence.

This system will use Texas Instrument's CC3100 SimpleLink Wi-Fi Network Processor as the controller interface between the MCU and the internet. The proposed solution offers its own ARM MCU to handle network processing protocols such as TCP, UPD, and IP which will save the system's main MCU from having to handle the various networking tasks. Also featured is WPA2 security for connection to most Wi-Fi hotspots. The Wi-Fi controller will be able to communicate with the MCU through either SPI or UART and contains integrated DC-DC conversions so that a wide range of supply voltages can be used. One concern has to do with the power consumption of such a chip which naturally will need lots of power whenever transmitting or receiving data over the Wi-Fi channels. TI's network processor, however, features many advanced low-power modes that will help in conserving power while the controller is not working to send or receive data. The final motivation for choosing TI's solution for connecting an embedded application to the internet is the company's vast library of documentation and support which they provide so that developing and integrating their product into our system is made easier and with added confidence.

It is important to discuss how exactly the Wi-Fi controller will bridge the gap between the MCU and the mobile application. This starts off with the interface to the MCU which will be implemented using the UART protocol. Given the serial nature of UART, communication with the MCU is fairly straight-forward and will therefore not be discussed in detail. The more complex side is how the Wi-Fi controller interfaces with the mobile application. This is accomplished through an external antenna that will need to be appended to the design of the system in order to receive signals over the air. As with any Wi-Fi system (or any wireless system where data is transmitted wirelessly through varying frequencies) the Wi-Fi controller will only operate on the network frequencies through the 2.4GHz channel. To ensure all data received from the antenna meets this requirement, a bandpass filter will be used to block out the unwanted frequencies. These extra parts will then allow the Wi-Fi controller to connect to the internet which will in turn allow communication with the mobile application.

It is interesting to note, however, that various other hardware elements will be needed in order for the Wi-Fi controller to operate on the data received through the air. TI's Wi-Fi Network Processor only contains 7KB of code memory and 700B of RAM on chip for various integrated processes. The full use of the controller requires a separate flash memory storage be connected to the chip for storing system files, configuration files, web page files, and user files where it is recommended that at least the size be at least 8MB for an encrypted file setup. Also required are two different types of crystals for clock input: a typical 32.768kHz crystal and a 40MHz crystal. The former crystal is used for the real-time clock and has the option of being inputted from somewhere else in our system that may already be generating this frequency. The latter crystal is important for use by the internal processor and the WLAN system within the controller. It too can receive input from somewhere else in the system that may already be generating the appropriate frequency. Figure 36 shows the pin configuration that will be used along with Table 23 showing the parts and their cost that will be utilized.

It should be noted, however, that the TI CC3100 was not used as the final choice for the Wi-Fi controller due to complexities that arose when integrating with the Tiva-C microcontroller. Instead, the Espressif ESP8266 Wi-Fi module was used which allowed for easier integration with the Tiva-C through simple AT commands that could be sent through UART. This reduced the integration design to pulling out the important data received by the Wi-Fi module from the UART Rx buffer.

Item	Name	Manufacturer	Part #	Quantity	Cost ($)	Total
1	0.1uF Capacitor	Taiyo Yuden	LMK105BJ104KV-F	12	0.10	**1.20**
2	4.7uF Capacitor	Samsung Elctro-Mechanics America, Inc	CL05A475MQ5NRNC	3	0.21	**0.63**
3	1.0pF Capacitor	Murata Electronics North America	GJM1555C1H1R0BB01D	1	0.15	**0.15**
4	22uF Capacitor	Taiyo Yuden	AMK107BBJ226MAHT	2	0.10	**0.20**
5	10uF Capacitor	Murata Electronics North America	GRM188R60J106ME47D	1	0.15	**0.15**
6	10pF Capacitor	Murata Electronics North America	GRM1555C1H100FA01D	2	0.10	**0.20**
7	6.2pF Capacitor	Kemet	CBR04C609B1GAC	2	0.29	**0.58**
8	100uF Capacitor	TDK Coporation	C3216X5R0J107M160AB	2	1.24	**2.48**
9	Ant Bluetooth WLAN Zibee WiMax	Taiyo Yuden	AH316M245001-T	1	1.95	**1.95**
10	Filter Bandpass 2.45 GHZ WLAN SMD	TDK-Epcos	DEA202450BT-1294C1-H	1	0.51	**0.51**
11	3.6nH Inductor	Murata Electronics North America	LQP15MN3N6B02D	1	0.18	**0.18**
12	2.2uH Inductor	Murata Electronics North America	LQM2HPN2R2MG0L	1	0.34	**0.34**
13	CC3100 802.11bg Wi-Fi Processor	Texas Instruments	CC3100R1	1	12.35	**12.35**
14	IC Flash Memory 8Mb 75Hz	Winbond	W25Q80BWZPIG	1	0.86	**0.86**

Item	Name	Manufacturer	Part #	Quantity	Cost ($)	Total
15	32.768KHZ Crystal	Abracon Corporation	ABS07-32.768KHZ-T	1	0.63	**0.63**
16	40MHZ Cyrstal	Epson	Q24FA20H00396	1	0.82	**0.82**
Total						**23.23**

Table 23: Wi-Fi Interface Controller Bill of Materials

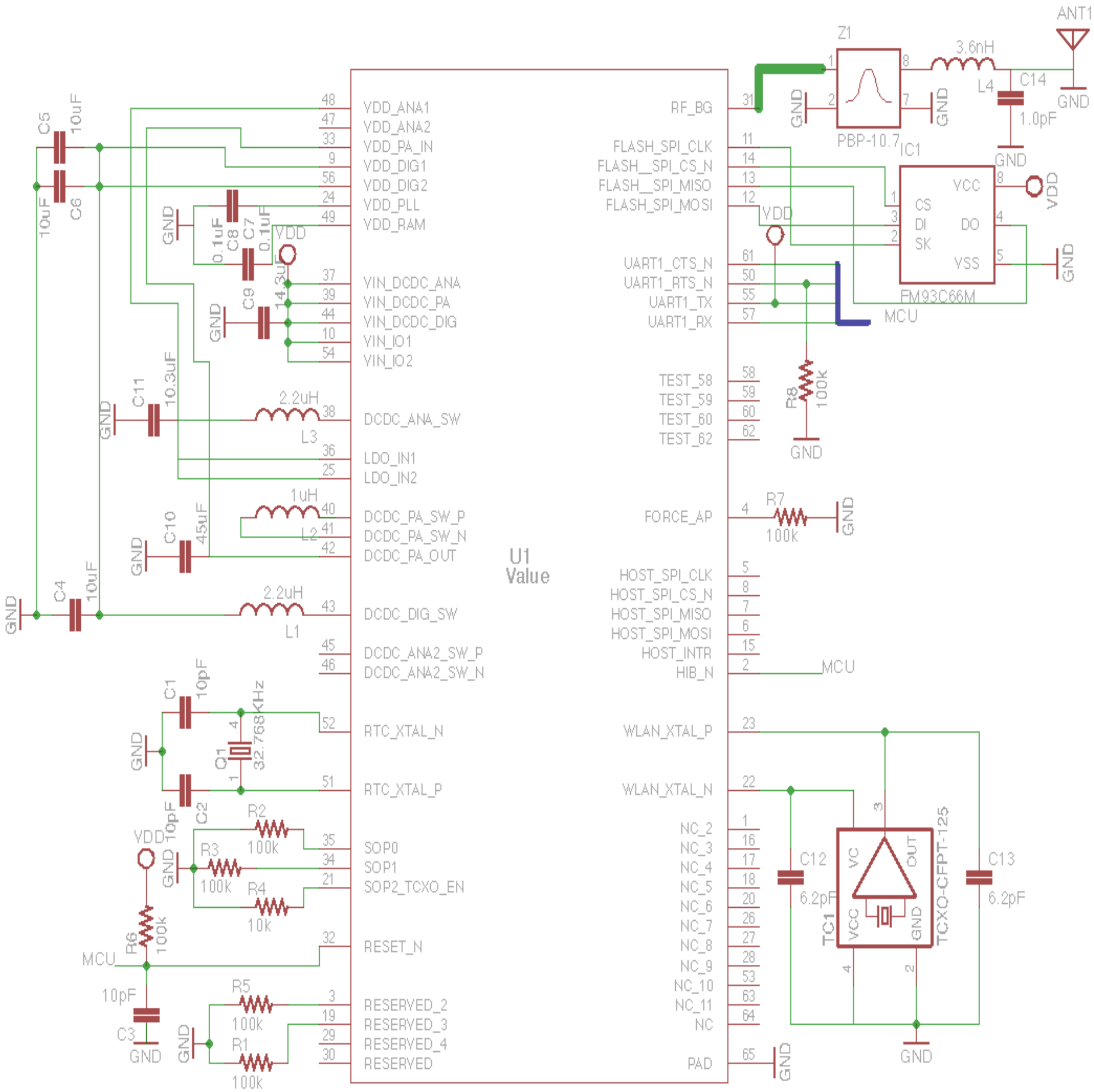

Figure 36: Wi-Fi Interface Controller Schematic

6.3.3 Layout

Having considered the concepts of how and why the mobile application and the display will work it is also important to discuss what sort of layout the user will experience when interacting with the system through either device. This section will identify key controls and information that will be available to the user and how those controls/information will be presented. It is important that all information is presented to the user in a clean and concise way with no one setting, control, or piece of information being too far from the user's grasp and yet keeping the interface simple and intuitive to use.

6.3.3.1 Home Screen / User Controls

The most important screen to be presented to the user, which applies to practically any system containing a graphical user interface, is the home screen. People today want to be able to see the information they're most interested in very quickly with all of the important controls to change that information made readily available in a simple and intuitive fashion. A home screen serves to sate this desire for the user by providing information about the system that is most relevant and recent. This screen presents the ability for the user to manage certain aspects of the system through control buttons that may have a direct impact on the system or by bringing new pages of information such as with most settings screens in mobile applications and operating systems today. Since this screen will be viewed more often than any other screen of the user interface, it is critical that the layout of the information and controls be intuitive and concise making sure that the most crucial information is presented in a bold manner while less critical pieces are available in a light but still elegant manner.

When managing a compost pile there are very few crucial pieces of information, namely temperature and humidity. This leads to a layout of the home screen that emphasizes these two characteristics of the user's compost above all other information. However, the automatic composting machine features two other useful components that will be of interest to someone using the system: the charge level of the battery and the level of water in the water container. The layout of these four useful sections of information are shown in Figure 37 as being front and center with the temperature and humidity data being slightly larger so that when the user opens up the mobile application they can easily and quickly know what the temperature and humidity of their compost is while also intuitively gathering data about the water level of the water container and the charge level of the battery. The display which the user interacts with directly on the composting machine is designed slightly differently but will be the same view as seen on the mobile application in landscape mode. Figure 38 shows that the discussed information is presented as one row with temperature and humidity being the first two columns in that row so that it catches the user's eye first and foremost with the battery level as the last column since it is least relevant in the list of presentable information.

Two more useful pieces of information that will be available to the user are alerts and an estimation or status of the compost. Alerts are presented to the user in a separate pane below the major sections of information as seen in both Figure 37 and Figure 38 where if there are no alerts, a general status of the compost will be displayed otherwise an alert appears and will be bolded so that the information demands the user's attention over other aspects of the screen. Another pane below the alerts pane in Figure 37 (or to the right of the alerts pane in Figure 38) will toggle as either a setup control or completion estimation of the compost. If there currently is no compost inside the system, then this pane acts as a control to the user for initiating the compost process and will bring up another dialog box for the user to enter information about the material that they have or will be inputting into the composting machine. If the user has already initiated the composting process, then this pane will act as a channel for information on the estimated time to completion of the compost that is in the system.

Another critical aspect to the home screen is the presentation of controls and navigation that allows the user to interact with the system and see more data about the system which may not be as relevant to the user except on occasion. Controls are important for the user to have easy access to and therefore are represented in both Figure 37 and Figure 38 as a pane at the bottom of the screen. This presents the controls in a simple fashion that allows the user intuitive access to different management of the composting machine. Both the fan and the misters can be controlled through the bottom pane, each of which will bring up a dialog box requesting more details as to what the user would like those hardware components to do. The third control in the bottom pane will allow the user to navigate to a landscape only page which shows historical information about the system which will be discussed in section 6.3.3.2 in greater detail. The last control in the pane will open up the settings screen giving the user greater control over the less important and less often used features of the system such as network information, machine/device pairing, and setup for manual operation of the compost machine. Only two other controls are not located in the bottom pane: the setup control which has already been discussed and the power button which is located at the top right of the screen. Power to the system is the control anticipated to be used least often by the user throughout the entire life of the machine since the system is powered strictly by solar energy. Due to this reserved use it is beneficial to place such a control in a place where the user will not on occasion accidentally press the button. Although a dialog box will appear to gather confirmation if the power button is pressed, it is best to minimize these accidental user inputs so that the user does not get annoyed with the placement of the control.

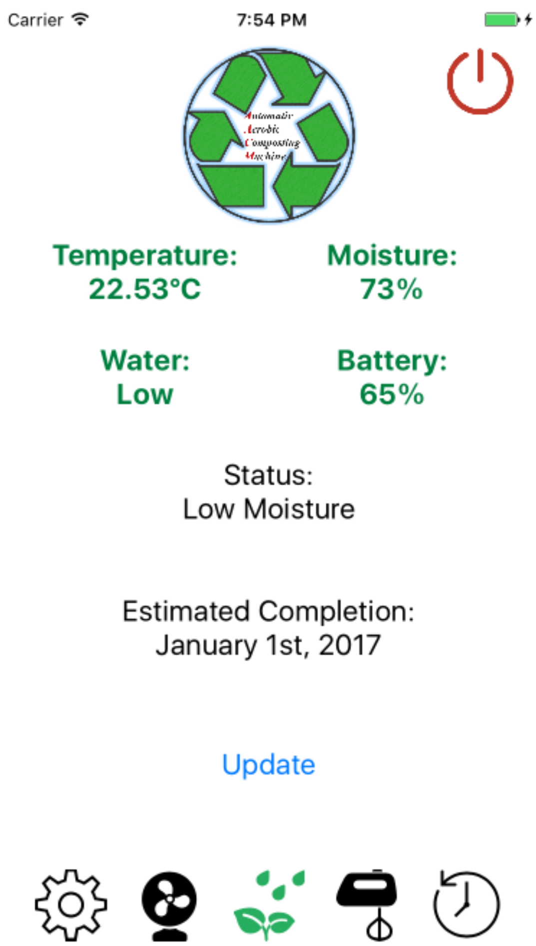

Figure 37: Mobile Applicaiton UI (Portrait)

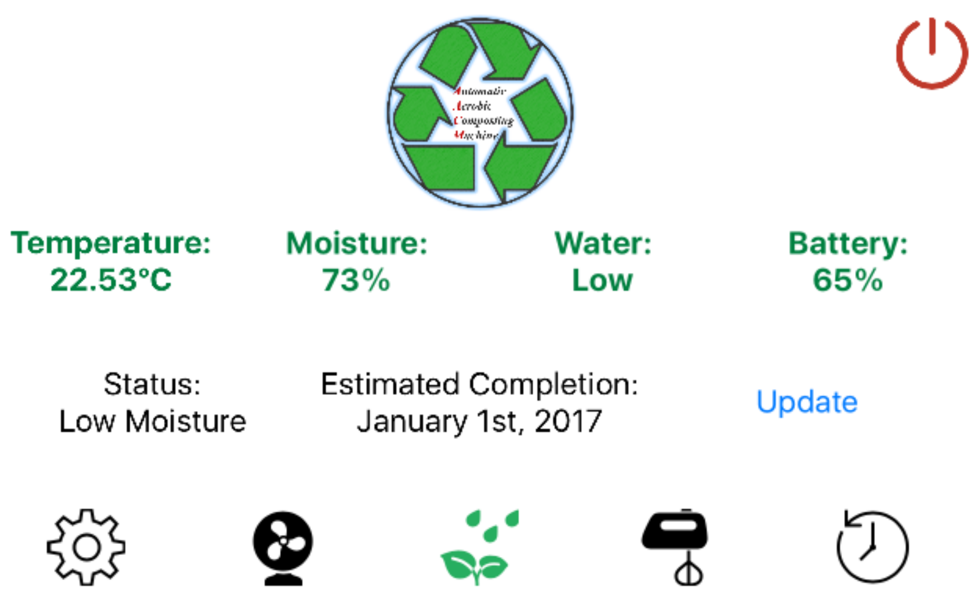

Figure 38: Display and Mobile Application UI (Landscape)

6.3.3.2 Usage Statistics

While all relevant and useful information should try to be presented to the user on the home screen for quick access to the data, there are certain pieces of information that cannot be presented in the context of a home screen. This is exemplified through the presentation of historical data which, by nature, cannot easily nor elegantly be presented to the user along with all of the other aspects of the home screen discussed in section 6.3.3.1. Therefore, a separate page for historical information is needed in order to take advantage of the newly found space that can be used to best present this data to the user.

The intent of the history screen is to present statistical data on the history of three main components of data from the system: Temperature, Humidity, and Power consumption. It was discussed in section 6.3.3.1 that temperature and humidity data would be displayed on the home screen, however, that data would be the most recent and there the most relevant to the user (which is valid information to display on the home screen as discussed). This screen, however, will present to the user how the temperature and humidity have changed over the course of the entire composting process. As shown in Figure 39, this screen takes full advantage of the entire space by presenting a large graph showing both temperature and humidity side by side so that they can easily be compared by the user without having to switch back and forth between two different graphs. A key/legend will be shown at the bottom of the screen to differentiate the two lines of data and a control at the top left of the screen will remain so that the user can navigate back to the home screen when desired. A graph of power that the system has consumed over the course of the composting process will also be displayed and can be navigated to by having the user swipe to the left or right, there by switching between the two useful graphs.

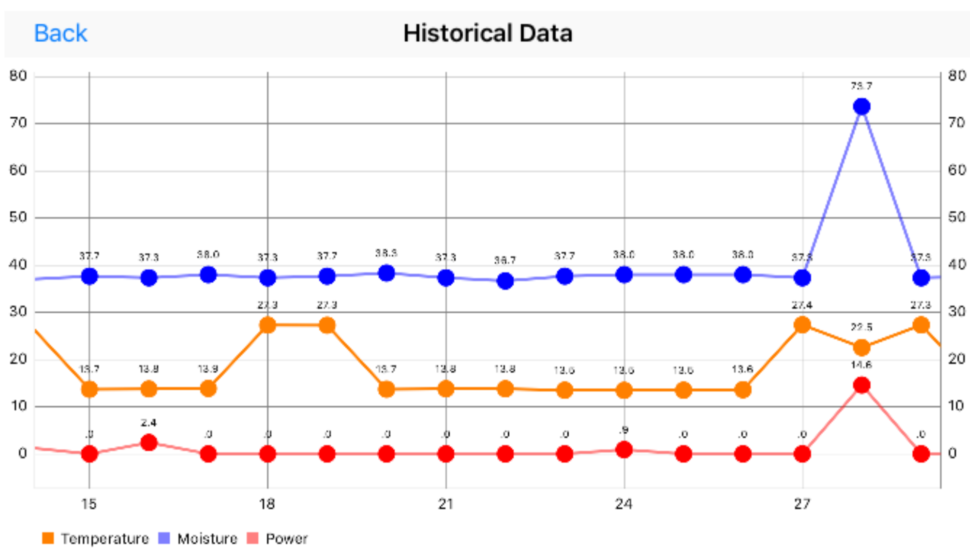

Figure 39: Historical Page UI

6.4 Software Design

Software is a major aspect of the system as it dictates how the different components will function with each other, as well as the effectiveness based on how the software are implemented. The design for these software needs to be able to tackle various issues such as compatibility, extensibility, modularity, reusability, security, and scalability. Having a good design allows for the system to effectively process compost and output optimal products.

6.4.1 Microcontroller

The microcontroller is one of the two major components, the other being the mobile application, that are directly controlled by software. The microcontroller deals with incoming inputs, analyzes the values, and determines what to do based on the results. Thus, it will need a good control algorithm to manage the peripherals under various scenarios such as high temperature, low moisture, etc.

6.4.1.1 Control Algorithms

Control algorithm is an important characteristic that should be one of the first things to considered when designing software. It describes how the components will behave and interact with each other and provides solutions to any problem that occurs. This section shall discuss the decision-making flow for the peripherals that communicates with the microcontroller and how it will operate based on the different situations.

6.4.1.1.1 Sensors

All six sensors (three of each type) that are located inside the mixing container will be continuously sending information about the compost to the microcontroller. The temperature sensors will be bounded by two variables with user-set values. If one out of the three sensors detects a temperature value outside of the bound values, a warning flag will be set so that the microcontroller will know about the problem. Depending on whether the temperature value is above the upper bound or below the lower bound, the sensors will set the specific warning flag matching the respective situation. The moisture sensor will also work the same way by setting the warning flags for the microcontroller to analyze when the sensors detect a value out of bounds. All sensors will also verify if the composting process has finished through the use of another flag that will be set by the microcontroller. If not, then they continue to take in inputs and repeat the cycle. This algorithm is shown in the form of a flowchart in Figure 40.

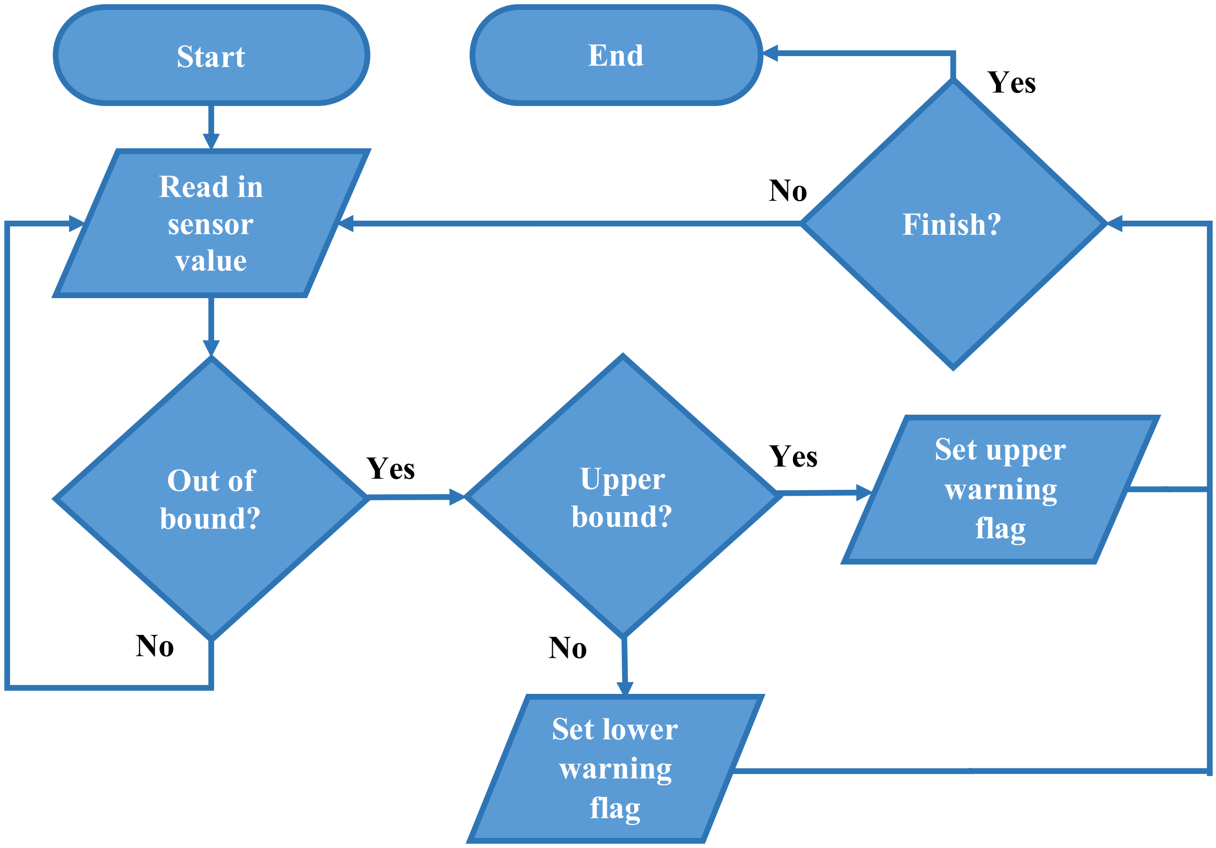

Figure 40: Control Flowchart for Temperature and Moisture Sensor

The water level sensor operates a little differently as it is an infrared distance sensor. The sensor will be bounded also by two values, but the values will be for when the water tank is low and when it is empty. The sensor will continuously measure how far away the water surface is relative to the top of the water tank, which is where the sensor will be located, and send the information to the microcontroller. Once the water level reaches a certain distance away from the sensor, it will set a warning flag to notify the microcontroller of the problem. The flag will stay set until the water level is refilled above the low water mark. This algorithm is shown in the form of a flowchart in Figure 41.

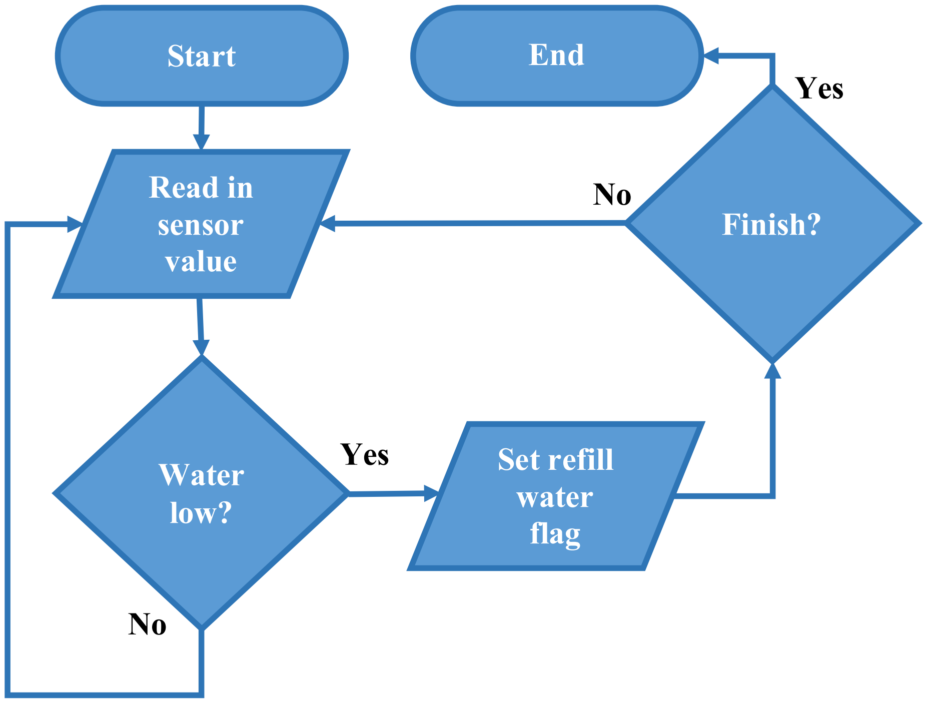

Figure 41: Control Flowchart for Water Sensor

6.4.1.1.2 Motor

The motor will be constantly rotating at a very slow RPM to prevent clumps of compost from developing and to constantly and evenly distribute oxygen throughout the pile. There will be a trigger coming from the temperature and moisture sensors through the microcontroller, where if the temperature and moisture content values are either too low or too high, then the motor will be sped up in order to more uniformly distribute the air, temperature, and moisture throughout the compost. By doing this, combined with the operations from the water pump and the fan, it can help to increase or decrease the internal temperature and moisture content of the compost. After a calculated amount of time, the motor will slow back down to its starting RPM. After that, if the sensors' readings still have yet to improve, then the motor will be sped up again, thus repeating the process until the sensors' readings are stabilized. The motor will stop operating after receiving an ending signal from the microcontroller. This algorithm is shown in the form of a flowchart in Figure 42.

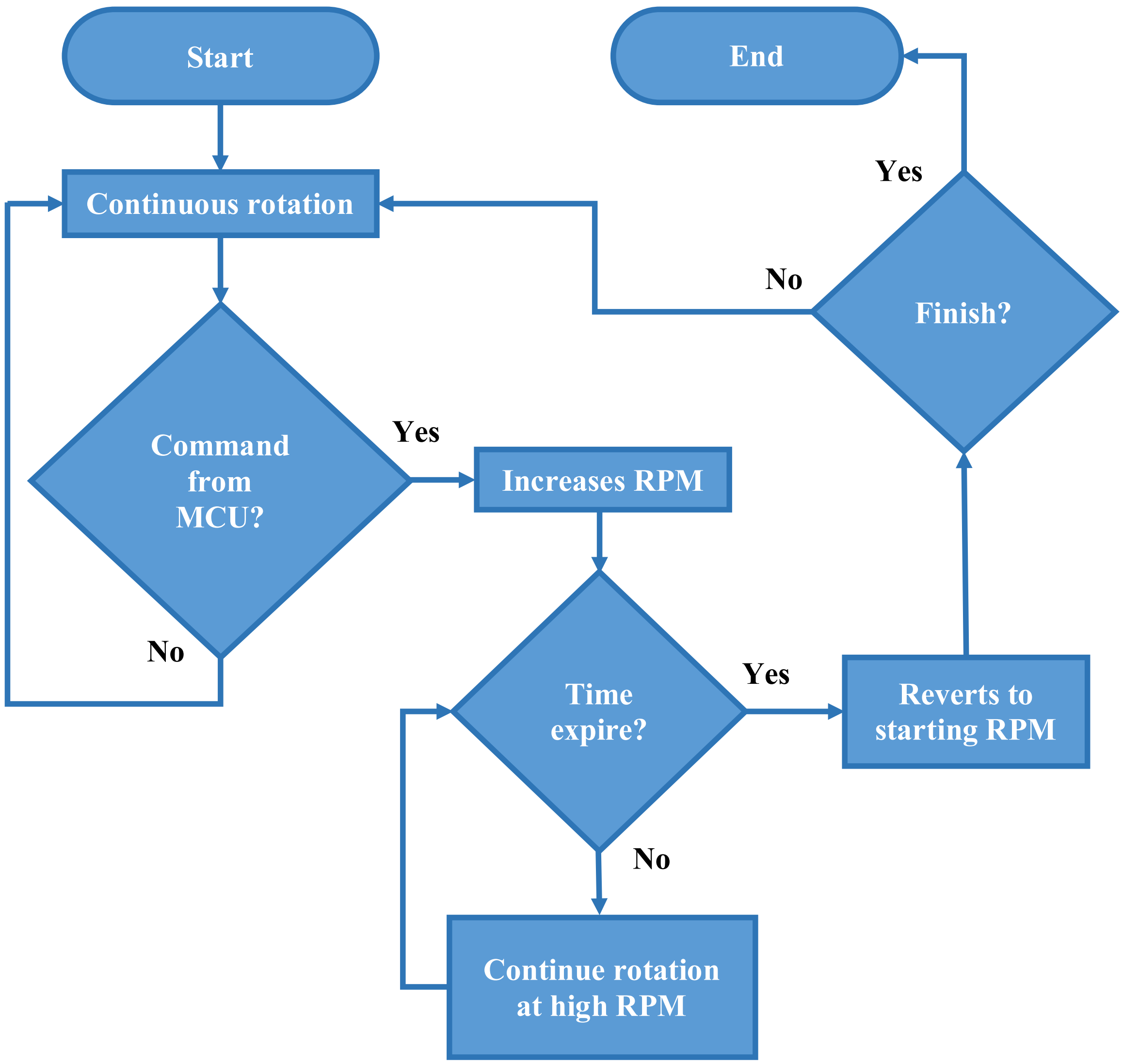

Figure 42: Control Flowchart for Motor

6.4.1.1.3 Water Pump & Fan + Relay

The fan will stay running to allow for constant airflow into the mixing container. This helps to reduce the bad smell produced by decomposition as well as to keep the microorganisms that break down the compost, alive. The fan will be controlled by a switch relay. In a normal composting cycle, the fan will be switched on when the microcontroller sends a signal to the relay and will stay on for most or all of the process. The fan will stop operating after receiving an ending signal from the microcontroller at the end of the composting process. The water pump will also be connected to the microcontroller via a switch relay. Whenever the microcontroller sees fit, an on signal will be sent to the switch relay which will then enable the water pump. The pump will stay on for a short duration of time, estimated by how much water per second will be pumped into the mixing container. The microcontroller will then send an off signal to the relay to turn off the pump. This algorithm is shown in the form of a flowchart in Figure 43.

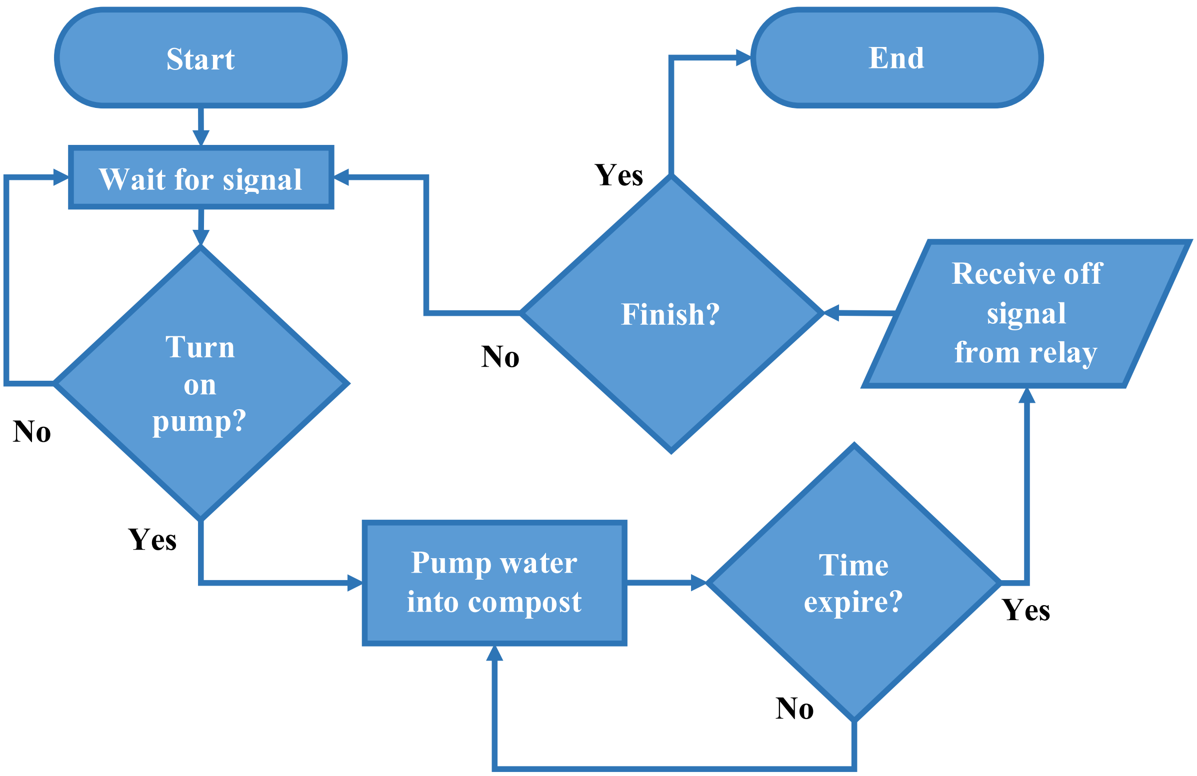

Figure 43: Control Flowchart for Water Pump and Fan

6.4.1.1.4 Display + Controller

The LCD will be connected to the microcontroller via an LCD controller that processes and formats the information to be displayed. As the microcontroller constantly receives sensors' data, it will continuously send that information straight to the display. Although, this will depend on which screen the LCD is displaying and what information is needed. Thus, if the LCD is on a page that is not displaying anything pertaining to the system, the microcontroller will halt its transmission to the display to save resources. On the other hand, if the LCD is on a page that requires certain information, then the microcontroller will send that information along with new ones to the display so that the user will see live updates on the screen. The microcontroller also will send over any warning messages that needs to be displayed as it processes the values from the sensors. This algorithm is shown in the form of a flowchart in Figure 44.

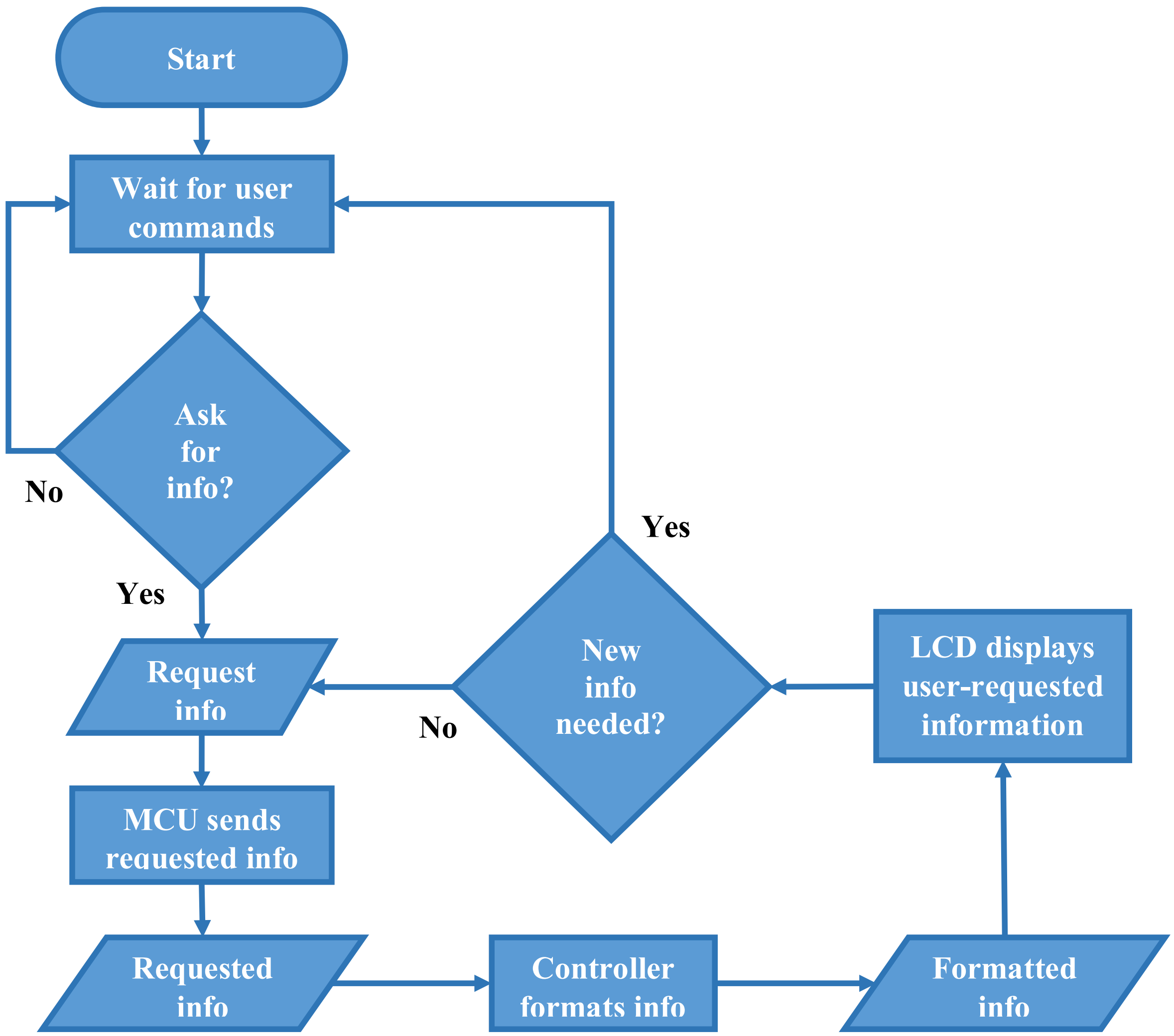

Figure 44: Control Flowchart for LCD Display + Controller

6.4.1.1.5 Microcontroller

At the top of the control system sits the microcontroller. It sends out commands accordingly to the rest of the system based on the information that it gets from the sensors' readings. For temperature, if the microcontroller sees that the warning flag saying that the temperature is too high is set, then it will send out signals to increase the speed of the motor in order to cool down the compost by heat distribution and more ventilation. This command process also applies to other situations as well. For too low temperature and high/low moisture content, the motor will also be sped up. However, for low moisture content, the microcontroller will also calculate a necessary amount of water to be pumped into the compost and sends an on signal to the switch relays to enable the water pump. The motor then distributes the water throughout the compost. Once the process is finished, the microcontroller will send a signal to terminate the processes and components' functions. This algorithm is shown in the form of a flowchart in Figure 45.

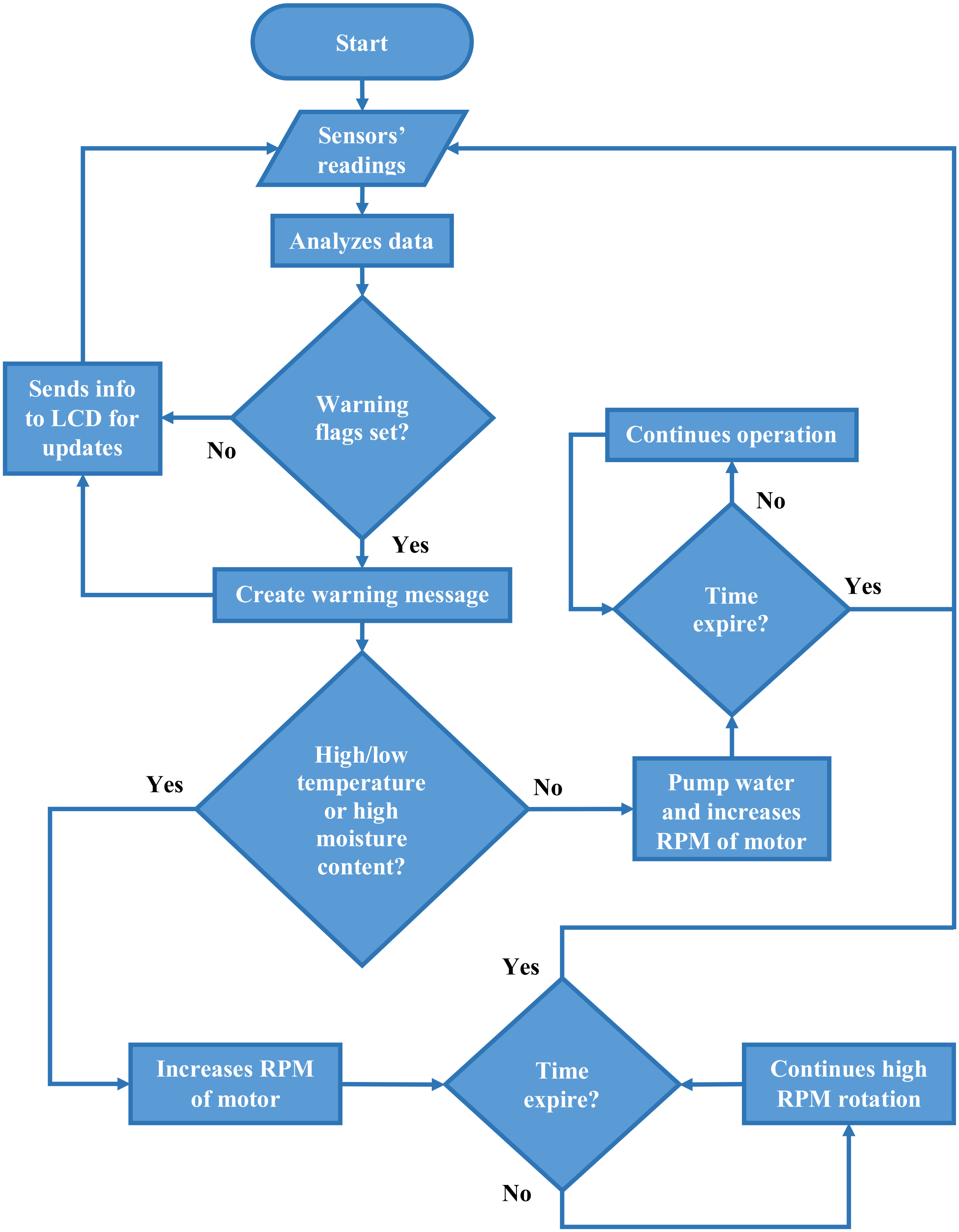

Figure 45: Control Flowchart for Microcontroller

6.4.2 Mobile App

This section serves to detail how the software for the mobile application and the cloud service will be implemented. As discussed in section 6.3.2.1, Apple's iOS platform will be the choice operating system on which the mobile application will run. However, a final component is needed to bridge the gap of communication between the mobile application and the Wi-Fi controller discussed in section 6.3.2.2. This void will be filled by Microsoft Azure which provides many services in the back-end that would have otherwise taken a lot of time and resources to develop and maintain. However, in order to provide a simpler time in development for communication between the system and the mobile app, an open online platform was used called ThingSpeak.

6.4.2.1 User Control

Microsoft Azure is a cloud service which offers many aids for IoT applications where the possibility of billions of devices will be connected, gathering and sending millions of messages every day. It is important, therefore, to use a service such as this for the automatic composting machine to establish, early on in development, a sound connection and familiarity with what the cloud has to offer. If this product is marketed well and becomes sought after by people all across the nation, the number of units could grow exponentially resulting in thousands or even tens of thousands of composting machines, all of which need to connect to each of their user's smartphones through a mobile application. Using Microsoft Azure will bring confidence that an environment like the one described will easily be supported with little to no changes needed in order to provide all customers with a reliable, secure, and enjoyable device.

In order to establish communication between the mobile application and the composting machine, a connection must be made where device authentication is achieved. To accomplish this Microsoft Azure's preconfigured solution of remote monitoring will be adapted to account for the specific hardware used in the composting machine (namely TI's SimpleLink Wi-Fi Network Processor discussed in section 6.3.2.2). This will ensure correct setup and provide data to the mobile application. Development under Microsoft Azure will be completed using the C programming language which provides familiarity and ease of coding to the development team since it is one of the better known languages. Microsoft also provides many examples of solution code that merely need to be adapted to fit the specific needs of TI's CC3100 chip. In order to prepare the future maintenance of the system for a larger scale of customers, a IoT device SDK will be used to provide building blocks that will help automate this service for the user. This will allow direct communication between the user's mobile application and their specific composting machine, making the process of pairing the two extremely simple and easy to implement on an individual basis.

Although Microsoft Azure would be the ideal service to use for a scaled up version where hundreds of devices would need to be communicated with, the purpose of this prototype is easily sufficed by a simpler platform called ThingSpeak. This service is completely free but does include limitations such as only eight different fields can be uploaded and any updates to the data can only occur once every 15 seconds. Communicating with ThingSpeak was achieved using simple HTTP requests since the mobile app and the physical unit are simply clients with regard to ThingSpeak. This allows all data to be retrieved as often as the client would like through simple means that are already implemented in iOS core development. Specific commands were implemented, however, through a custom API which would send the correct request through customized functions and would parse the data received for the caller.

6.4.2.2 Security

Security is one of, if not the most, crucial aspect to any system in today's market that connects to the network of networks commonly known as the Internet. Customers generally worry about how secure the platforms they're using are and will even make decisions based on whether or not the certain application or device they're using is secure enough for the task they are wishing to implement. This is evident through features and software that has now become commonplace: Norton Antivirus, private browsing modes in web browsers, fingerprint scanners in smartphones, the all too common message that a password needs to be changed after a certain period of time, and even solutions as simple as entering a four-digit number in order to unlock your mobile device. With the great cloud of solutions to security being so forefront in more people's minds today, it is important that the automatic composting machine automatically provides users with a platform that has security levels implemented to make sure device hacks and exploits are not used to affect the user's compost at any point in the composting process.

Looking at the major components of software that the automatic composting machine will implement, it is clear that there are three areas where security is of a vital concern: the mobile application residing on the user's smartphone, Microsoft Azure, and the controls which directly control the composting machine through the LCD. Microsoft Azure's IoT Suite is a very professional and highly sophisticated service through which many engineers and developers have worked to produce an IoT solution that not only operates to large scales but also provides a reliable and secure environment for the devices connected to its platform. Microsoft Azure uses a Service Assisted Communication approach which employs many principles that implement a high level of security for device interaction, ensuring that notifications, telemetry, inquiries, and commands are all sent to the appropriate device and are responded to with the same level of confidence. Further interest in Microsoft's approach is detailed in "Service Assisted Communication for Connected Devices" [17] and will likewise not be discussed here.

With Microsoft Azure being the arguably most secure between the components mentioned, it can be said that the mobile application will comprise of the second most secure platform of the three. This is due to the vast improvements in security that smartphone makers have implemented in their devices recently, making it extremely hard for hackers and thieves to break into another person's smartphone. This in turn provides higher security for the automatic composting machine since it will be harder for anyone except the owner to access the mobile application. However, in case of such an event, an extra layer of security will be developed to further protect the user's composting operations. The mobile application will feature a prompt the first time the user opens the app to login to their account, hosted by Microsoft Azure, which will connect them with their own composting machine. Subsequent openings of the app will require either a user defined four-digit passcode or can be configured to use Apple's Touch ID feature to grant control to the user's composting machine. There will be settings, however, to disable these features if the user decides to choose convenience of quicker access to control of their composting machine over security. Finally, the composting machine itself will be given a simpler security feature of requiring a passcode to be entered on the display, when it is awoken from sleep mode, which will grant access to the user upon the correct digits being entered.

6.4.2.3 Control Exhibition

When developing the mobile application, there will be two main components that will be utilized from Apple's iOS programming language, Swift: UIButtons and UIViews. These two classes offer all of the fundamental methods and connections needed in order for them to seamlessly work with Apple's iOS devices. This allows the programmer to focus on implementing the rest of the class and even adding subclasses that fashion the mobile application towards the intended design without worrying about the details of how to recognize a press, swipe, or other gesture of the finger. However, some attention to these predefined operations is required from the developer since system wide settings can be set by the user that may have an impact on the design of the UI, such as system font size, font style, notification settings, and other interrupts that may occur such as phone calls, messages/notifications from other applications, and the rare crashing of the system or application. These will be taken into consideration when developing the mobile application and test cases, discussed in section 7.2.3.1, will be run to insure that the application has an appropriate reaction and affects the user's experience in the least negative way.

All controls, inheriting their methods from the UIButton class, will be following a similar pattern for responding to user input, outlined in the sequence diagram in Figure 46. This process starts by the composting system providing the cloud service, run by Microsoft Azure, with the data about all of the different sensors and controls. It should be noted that the composting machine will be providing data about its status on a regular basis and is merely shown here to remind the reader where the information is originally coming from. When the user presses on a certain control button, the mobile application will then request the current status of that particular control from the cloud. The cloud will then retrieve the current status and provide it to the mobile application which will in turn use that data to prompt the user for a command or change that they want to implement for that control. This initial data is retrieved so that if the user gives a command to change a control to a status that it is already at, the mobile application can save time and not have to send a command request to the composting machine through the system. The importance of this lies in the fact that Microsoft Azure's pricing is based on the usage amount of the service. Therefore, to allow this system to grow to a large scale, the design needs to reflect keeping costs down when thousands of systems are connecting to the cloud. After the mobile application receives the current status information about the particular control, the user will be prompted for further action to verify what sort of command they want to give to their composting machine. For instance, if the user presses the fan control, the mobile application will prompt the user for either turning the fan on or off. The user will then give a command to the mobile application which will, in turn, relay that command to the cloud which will, in turn, con vey the command to the system. Once the system receives and implements the command, it will provide feedback to the cloud about the status of that control. The cloud will then update the current status for the control and send confirmation to the mobile application that the command was implemented. The user will then be informed that the command was received and implemented by the mobile application making the necessary UI updates to the control status.

Now that the details on how control buttons will work and operate, it is important to discuss the structure of the software. The class diagram in Figure 48 gives a detailed look into what controls will be used and how the attributes and methods flow from class to subclass. The highest class of concern for the architecture is the UIButton class which is provided by the Swift programming language and therefore is not detailed here. Inheriting from the UIButton class is the Control subclass. The Control class is made up of a Name, with a data type of a simple String, HardwareConnection, with a data type also of a simple String, and a boolean attribute, OnOff. The Name attribute is prepared in this class so that subsequent subclasses can be identified with a specific control and will make UI refreshes/updates much easier when implementing these buttons in the different views. A HardwareConnection attribute is needed to be able to simply and quickly identify which component of the hardware in the system is controlled by the specific control button. Since all of the hardware connections that are allowed to be controlled by the user also contain the same attribute of either be on or off, a OnOff attribute is needed with the true value implying that the hardware component is on while false implies the component is off. Two abstract methods are defined which allow for direct communication to the composting machine through Microsoft Azure and that allow for data updates to be reflected in the UI. The first method, SendCommand(), is responsible for relaying the command that is received from the user to the cloud and will be developed to work with Microsoft Azure's AMQP protocol. Figure 48 also shows that three subclasses will inherit from the Control class: the FanControl class, MistControl class, and the PowerControl class. FanControl has an added attribute of Speed, with a data type of integer, in order to provide the user with how fast the fan is rotating and to allow for future updates that may have the user specify a certain fan speed. MistControl has an added Pressure attribute, also with a data type of integer, to convey to the user what sort of pressure the misters are operating at. As with the Speed attribute in the FanControl class, this will allow future updates that may allow the user to control what sort of pressure the misters will use, which could be useful during maintenance or cleaning of the cylinder that holds the compost. The PowerControl class has no need for further attributes and therefore is simply an extension of the Control class. The SendCommand() method will be implemented for each of these three classes and allow for customization to each control.

Another set of controls will be developed to handle strictly in-app navigation. As Figure 48 pictures, the UINavigationController class, another class provided by Swift and not detailed here, is the high level class concerned with the design of these sets of controls. The Navigation subclass inherits from the UINavigationController class and will be developed to provide specific functionality of allowing the user to move from one view to the next and then back again. For example, moving from the home page to the settings page and then back to the home page. Attributes associated with this class are Name, with a data type of String, and Destination, which is actually a reference to an object of the UIView class type. The Name attribute merely identifies which type of navigation this object is meant to do and allows for easy updating of the UI through the UpdateUI() method. The Destination attribute will be a reference to the actual object of the view (or page) that is supposed to be shown to the user when the method GoToDestination() method is called. Therefore, when the user presses on a Navigation control, the GoToDestination() method is called and will use the Destination attribute to then provide the mobile application with the desired view that is to be displayed. Hence, why that method returns a UIView type of object as shown in Figure 48. There are three specific Navigation classes that will be used in the mobile application: the SettingsNav class, HistoryNav class, and the HomeNav class. None of these classes will require any extra attributes or methods and will simply implement the provided abstract methods from the Navigation class.

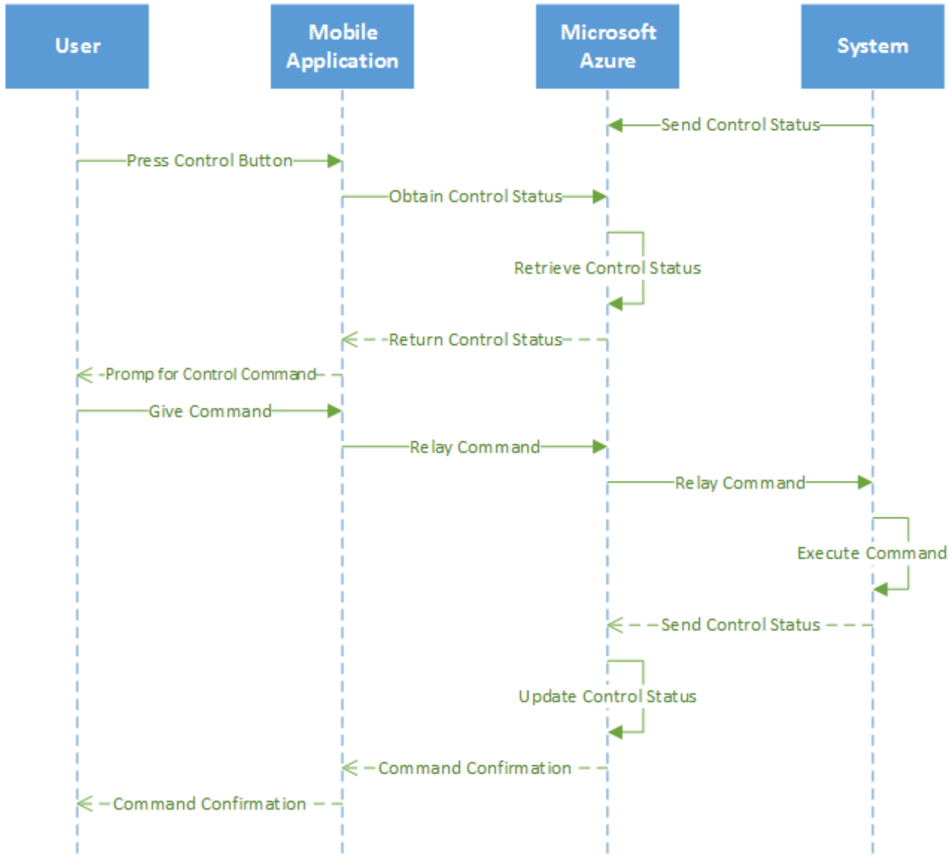

Figure 46: Control Buttons Sequence Diagram

6.4.2.4 Views

Having looked at how the controls and navigation will work within the mobile application, it is now important to delve into the different pages, or views, that the user will be exposed to and how the software is structured in terms of class hierarchy and methods that will be implemented. It may be beneficial at this point for the reader to refer back to section 6.3.3 to be refreshed on what the layout of the user interface will be for the home page and the history page as that will not be discussed in great detail here. The different objects on the home page that will display current conditions for temperature, humidity, water levels, and battery levels will need to gather data from the system through the cloud. This method is almost equivalent to the way that control buttons will gather their needed data as was discussed in section 6.4.2.4, however, with the slight change that there will be no need to gather user input or worry about transmitting commands back to the system. The history page inspires a different method for gathering data since current and previous data are desired. The sequence diagram in Figure 47 explains this method and starts off by emphasizing the use of Microsoft Azure to collect data from the system, which will be occurring on a constant basis. Whenever the composting machine provides updates about its status to the cloud, Azure will store the currently saved value for that specific piece of hardware (i.e. temperature sensors, humidity sensors, etc.) in a database either using DocumentDB or another in house SQL database. The next action on the sequence diagram represents the action of the user opening the mobile application causing it to request the current info for the temperature, humidity, water, and battery levels. The cloud will then provide the current info and allow the mobile application to display that data to the home page for the user to browse. When the user presses on the history screen navigation button, the mobile application will then request not just the current data but all historical data. Since this data comes in the form of an image from Microsoft Azure, the cloud will then calculate and format the charts required for the history page and then present them back to the mobile application. This will allow the history screen to be displayed to the user with all relevant historical data appearing in the form of graphs and charts as discussed in section 6.3.3.2.

Structurally, these pages will be individual classes which all inherit from Swift's UIView class. In Figure 48 it is shown that four different views are needed: HomePage, HistoryPage, SettingsPage, and a SystemData view. The HomePage class will consist of the automatic composting machine's logo, four other UIViews to display current data, three control buttons for the FanControl, MistControl, and PowerControl (as discussed in section 6.4.2.3), and two navigation buttons (also discussed in section 6.4.2.3). Unlike the controls side, where inheritance dominates the design, the HomePage shows inheritance of the UIView class but also will be composed of three other classes: the Control class, Navigation class, and the SystemData class. The unfilled diamonds in Figure 48 are present to show this composition relationship and to specify that there will be at least one object from each of those classes and could potentially be composed of many objects from those classes. Only two methods are needed: UpdateUI() and RefreshData(). The RefreshData() method will be used to instigate the four UIView classes, that present the current info about the composting machine, to gather the recent data from the cloud. Once that data is retrieved, the UpdateUI() method is then used to display to the user the most current information.

One class that the HomePage class will be composed of that has not been discussed yet is the SystemData class. Each of the four main sources of information will be from this class as shown in Figure 48 as the TempData class, HumidityData class, WaterData class, and the BatteryData class. Since a UIView can contain other UIViews that should be displayed to the user at the same time, it was tough to be prudent to split up the different methods and attributes that these data gathering views need. Therefore, the SystemData class will contain an attribute called Sensor, of the data type String, to indicate which piece of hardware it is relate to, and will contain two methods: RetrieveData() and UpdateDataUI(). As already mentioned, the HomePage will prompt these classes to gather the most current information about their specified sensor/hardware. This prompt calls the RetrieveData() method and then will provide that data to the class which will then call the UpdateDataUI() method in order to make it is reflected in the SystemData class as well as passing on the data to the HomePage class.

Lastly, the HistoryPage class and the SettingsPage class will both inherit from the UIView class and provide separate views for the user to browse. The HistoryPage class will be in charge of presenting the graphs and charts of historical data to the user and as such will consist of a TempHumGraph attribute and a PowerGraph attribute. Both attributes are of the UIImage type since they will simply be images obtained from the cloud and will be much easier to present to the user on screen. Two methods are needed: RequestData() and FormatGraph(). When the history screen is opened up, the RequestData() method is called in order to retrieve the images from Microsoft Azure about the current and historical information. This image may or may not be correctly formatted to fit on the screen of the user's iOS device. Therefore, the FormatGraph() method is called by the class in order to ensure that correct sizing and formatting of the image is complete before it is presented to the user on screen. The SettingsPage class is perhaps the simplest view out of all four that have been mentioned so far. On the settings page information about user preferences for their composting machine, the mobile application they're using, and network preferences will all be displayed to the user. This will be done through a short list of UIButtons for each distinct set of information which is why the SettingsPage class contains only four attributes: AppInfo, NetworkPreferences, UserPreferences, and HomeNav. The former three attributes will be references to objects of the UIButton class while the last attribute will be referencing the HomeNav object. Four methods are needed: NetworkInfo(), AppInfo(), Preferences(), and ShowCurrentView(). The first three methods are called whenever the corresponding button is pressed by the user and will gather information about the desired information and return that information in the form of a UIView object. This makes it easy for the SettingsPage class to then call the ShowCurrentView() method in order to display that desired view to the user.

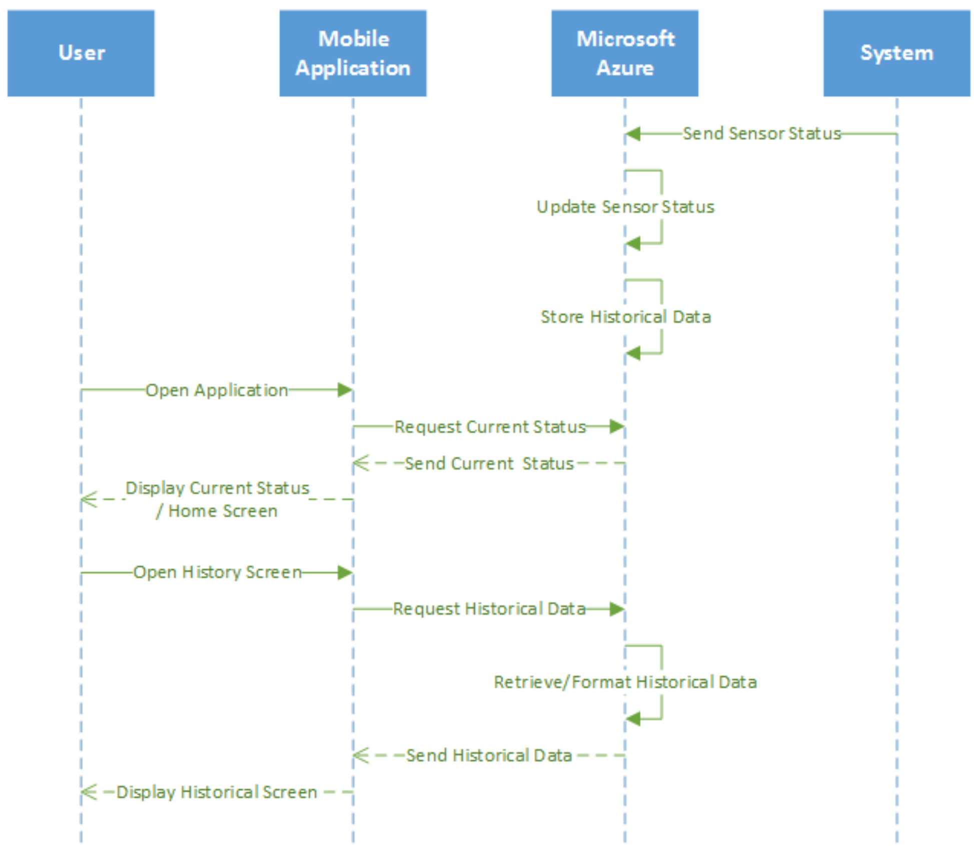

Figure 47: Data Gathering Sequence Diagram

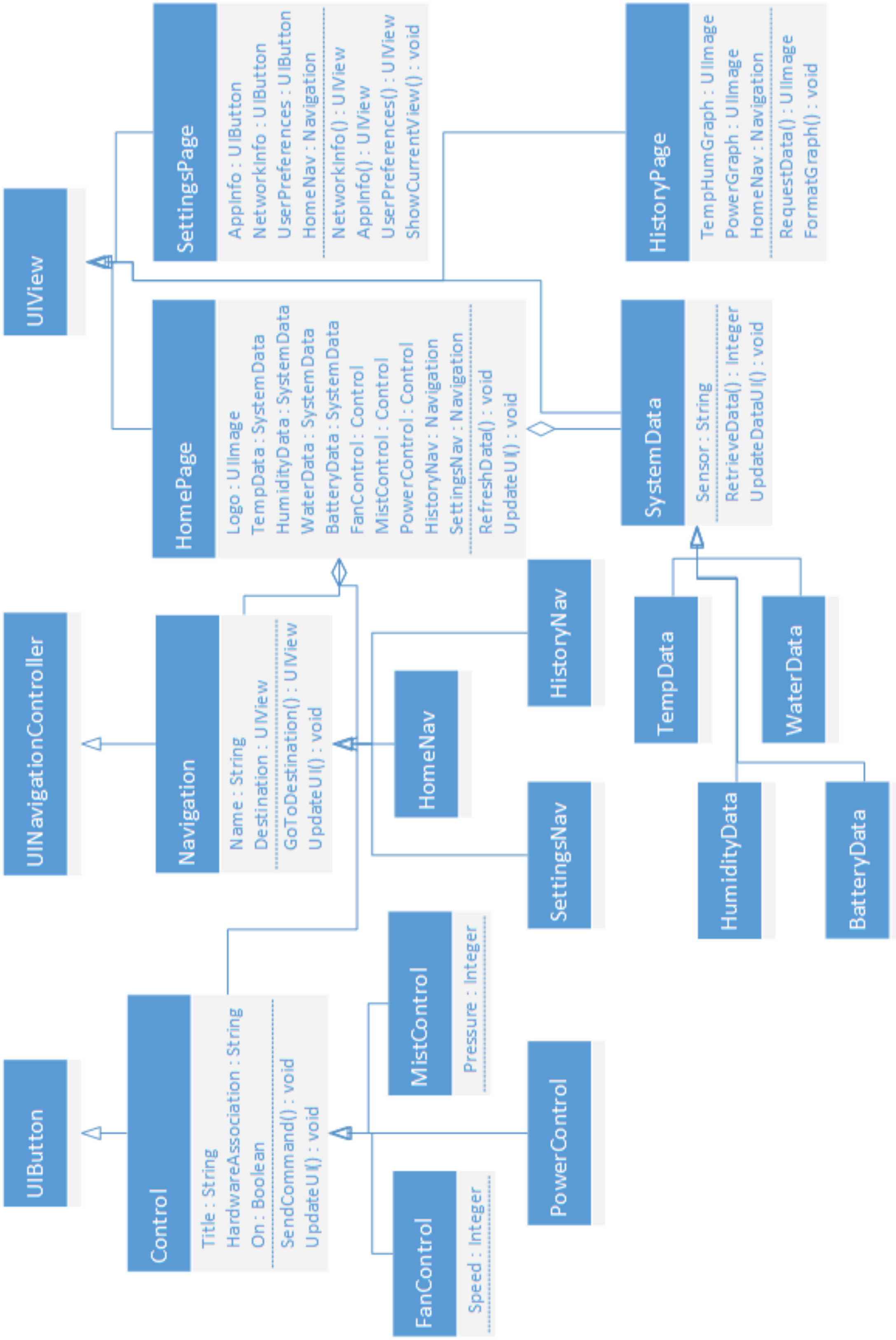

Figure 48: Mobile Application Class Diagram

6.5 Mechanical Design

In order to speed up the compost process, material must be turned to enable oxygen to flow from the exterior to the interior and carbon dioxide from the interior to the exterior. Movement and mixing also breaks up any clumps of material to prevent an unequal distribution of moisture and in turn the overall humidity average. As the system rotates, the material that was previously under the surface is able to be exposed to not only the air but the water as well. This design enables the composting material to be decomposing and breaking down at a uniform pace. It is important that the compost mixing system keeps all of the material breaking down at a uniform pace because if there is finished compost at the same time that some is unfinished, then it is very difficult to identify when a round of composting has been completed. This section includes a description of the components of the mixing system and how they interconnect. Each of these components is key in ensuring that the material is being mixed as designed and being broken down at a uniform pace throughout the composting process. They are the mixing container and external assembly, aeration system, and the sensor and misting mounting axle. In each section materials and sizes will be included where applicable and how each interfaces with the other components of the prototype. Table 24 presents a comprehensive bill of materials that will be procured in order to create the mechanical system.

6.5.1 Mixing Container and External Assembly

The mixing container is a conglomerate of different materials and tools. The overall goal of this system is to have a mixing container that is able to rotate independent of a support structure. The mixing container also must contain fins perpendicular to the inside surface to keep the compost material from sliding and lacking traction during rotation. The container must also be capable of simple emptying and refilling. Additionally, the container houses the six sensors and misting system. This system was also designed for simplicity and ease of interconnection. Since this system decreases the amount of time it takes to produce compost, the mechanical system needs to be able to be emptied and refilled as efficiently as possible. Additionally, the system components must be able to be easily replaced in the event of malfunction or damage. With this, the design is modular and can be broken down and rebuilt in an efficient period of time. The system utilizes a primarily transparent mixing system to promote the understanding of the integral components of our system. The transparency allows the prototype to show how the material is mixed and how effective the misting and aeration system is. Due to demonstration needs to prove overall functionality to observers, the prototype retains robustness and ability while also enabling visualization of how the system was designed and works. The ability to see inside the container also provides the end user during testing to be able to check that the internal components are operating as expected. The PVC and acrylic components that follow in sections 6.5.1.1 and 6.5.1.2 will be cut to custom sizes from larger pieces. This is done to reduce cost and simplify manufacturing.

6.5.1.1 The Shell (Rotating Component)

The shape of the mixing container is an octagonal prism. The prism will be made of eight acrylic pieces and will be 20 in length and 4.5 inches wide. Each of the eight sections will be fused together using a solvent that will melt the joints together and when allowed to cure, will be one solid piece. This method is used to ensure that the structure is rigid and will not leak or give way during rotation. It is important for the structure to stay intact as the mixing takes place since any structural issue with the mixing system during operation will hinder the composting process substantially.

Additionally, the moisture level must be able to reach a uniform level and if there is a breach in the seal of the adjacent acrylic panels, moisture could leak out causing an ineffective moisture control system that will in the end have dried out material and will cause recurring filling of the moisture system storage container.

On each of the eight panels on the inside of the container will be a two-piece acrylic edge that will assist in rotating the material effectively. Each piece will run along the 30 cm length of the panel and will be placed at the center. The two pieces will be fused in a similar fashion as previously described, but this is done so from a structural stand point. Having the two pieces chemically melted together is important because each of these blades will be helping lift and break up the compost material. The acute angle edge as shown in the Figure 49 in the left opening, has two pieces making up that blade. The side of one of the angle sides is chemically melted to the acrylic panel to ensure its integrity as a part of the system whole. As the prism rotates around its axis, the blades will keep the material turning over itself and provide an effective mixing technique to ensure uniform humidity and temperature. The two pieces of acrylic will be connected at an angle of roughly 45 degrees to make sure that the material is being pushed upwards in the same direction as rotation. While one panel rotates underneath the material, the blade is pushing material up the leading edge side, some material is caught within the angle. Next the blade is overhead and most of the material has fallen back into the compost pile. As the blade then returns to enter the leading edge of the pile the final amount of material is emptied onto the top surface. The edge component is key in bringing the material from the bottom of the composting pile to the top. These blades in conjunction with the aeration and moisture control systems is what optimizes the composting process effectively.

In the final mechanical system, some of the above details, such as specific lengths and angles were deviated from due to manufacturing limitations and feasibility. The final shell was 20 inches in length, and 11 inches tall.

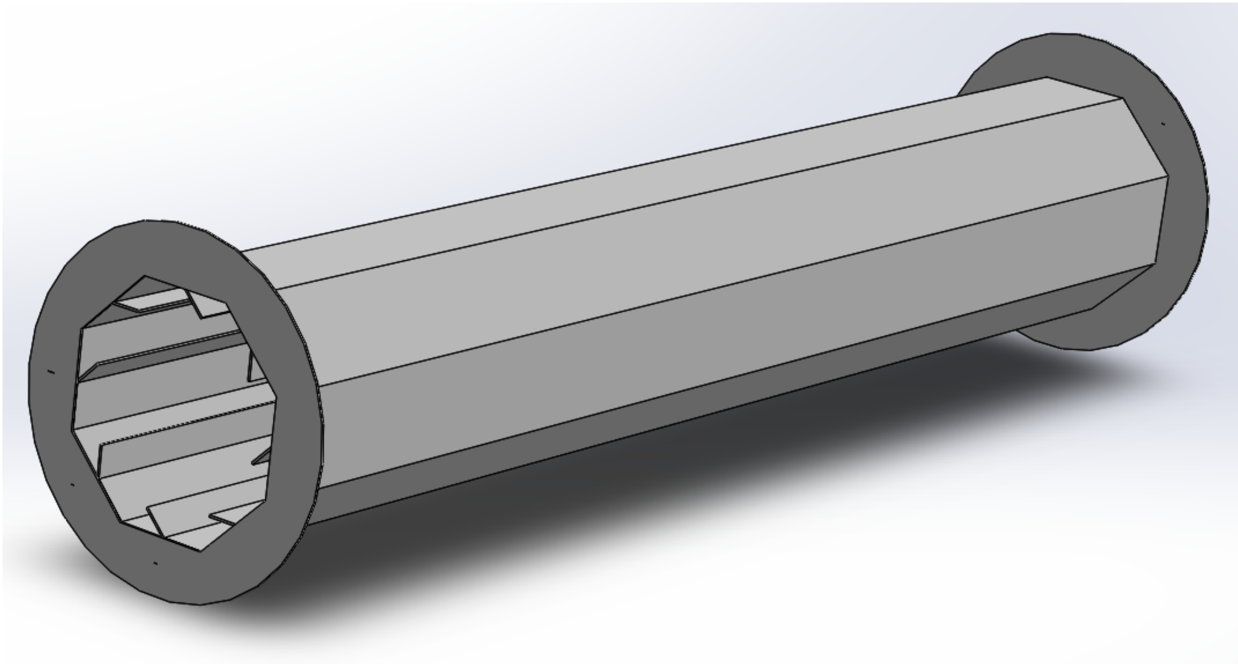

Figure 49: Mixing Container

A component of the shell will be an external sprocket placed on the outside of the octagonal shell. Not only will it be placed on the outside of the container, but it will be placed along the center of the octagonal prism. This piece is vital as it is what provides traction for the motor to rotate the octagonal prism and in turn the compost material. This sprocket will be made of acrylic, and will be cut to size defined from a file generated using Solid Works software. The inside of the sprocket will be an octagonal shape that has a radius of 40.45 cm, a size that is one millimeter larger than the outside of the octagonal mixing container. This one millimeter will enable the sprocket to slide to the center of the prism and be chemically bonded at the ideal location, dead center. The sprocket will become a part of the prism once the chemical process is concluded. This fact is important as it contributes to the overall structural integrity of the prism and will improve the durability of the overall mixing system. With the sprocket added, there will now be three locations that will be holding the eight panels of the mixing system in place, one from the center sprocket and two from the PVC rings that meet the leading and trailing edges of the prism. To enable simple attachment and removal of the side panels there will be a PVC ring that is 1.27 cm thick. The outer edge will be 47 cm in diameter and the inside diameter will be sized to have minimal overlap with the octagon shape to prevent material from being stuck on the inside of the container. The reason why the PVC will have an outer diameter of 47 cm is primarily due to the diameter of the external sprocket that is chemically fused to the octagonal prism. During assembly there can be a moment when the prism will be assembled but the other components haven't been created or attached yet, so if the mixing container is placed along its side, the sprocket teeth could be damaged if they are leaned on with an unexpected load. With the outer edge of the sprocket's teeth being 45.72 cm, the two side panels must have a diameter larger than that so they will receive the full load of the container and not the sprocket teeth. This ring will be chemically bonded to the ends of the octagonal prism and will serve primarily as a mounting point for the side assembly. This is a vital piece due to its ability to aid in easily removing the side panels for emptying and refilling material.

This piece will have eight holes to allow for threaded bolts to be placed through to the side panel assembly and be fastened by hand with the use of wing bolts. This is important since the purpose of this overall system is to make the composting process more efficient and will be emptied and refilled at a regular pace. Figure 50 shows the mixing container with the large diameter sprocket around the center of the long edge.

In the final mechanical system of the design, the gear and sprocket design was deviated from due to the limiting nature of available manufacturing practices and available sprockets. To ensure proper rotation, there was a large round piece of acrylic that was larger in diameter than the entire shell which had a smooth perimeter. The circular piece of acrylic was driven by the 12V motor at a constant rate through the use of a wooden rotor with rubber placed around it.

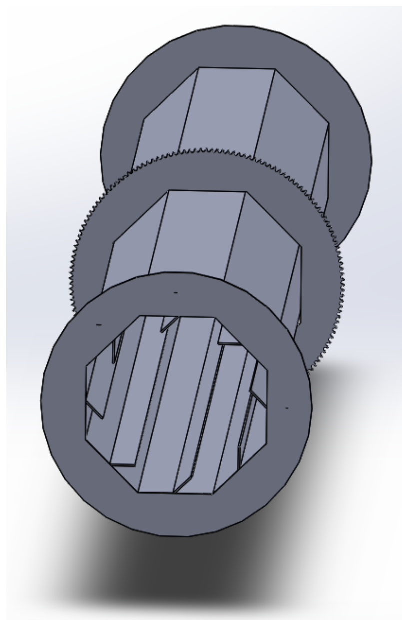

Figure 50: Sprocket on Mixing Container

6.5.1.2 Side Assembly

Both sides of the container play a vital role in supporting a majority of the mixing system comprising of the misting system, sensor mounting system, aeration system, bearing assembly, and structure supports that hold the container firmly. From the mounting ring that was mentioned in section 6.5.1.2.1, both end panels will be fastened to that component using the eight bolts. The ring of PVC will have the same outer diameter of 47 cm although will have a different inner diameter of 15 cm. When the bolts are connected, the overall structure will be an octagonal prism with two circular ends that contain 15cm circular openings. This entire structure is what will be the rotational portion of the mixing system. To enable the outside area to rotate freely, independent of the internal components and the base (support structure), the bearing assembly must be considered. This 15 cm hole size on the two ends of the mixing container is important because the inner radii of 15cm will be where the bearing assembly will be mounted. The bearing piece is made up of two concentric rings with four through holes for mounting hardware on each ring. The PVC side panel will be mounted to the outer bearing ring, with the bearing on the exterior side, away from the interior of the mixing container. The bearing will be mounted on the outside edge due to the ability to easily re-apply lubricating oil and perform necessary maintenance on the bearings. Additionally, with the bearings on the exterior, the bearings will have less of a chance of being affected by any composting material and debris. Before the screws are tightened in the four hole locations, there will be a sealant and adhesive that will help create a sealed perimeter and make the connection stronger.

On the inner bearing the first component that will be mounted will be a 1.27 cm thick ring that will be the exact diameter (9.9 cm) and size of the inner bearing. It will contain matching through holes to place a threaded bolt through running from the interior of the cylinder, outward. This ring will act as a spacer to prevent friction between the base structure that will remain in place as the outer bearing and mixing container rotate. This spacer will then be chemically bonded to an outer plate that will be 1.27 cm thick PVC and will be 10 cm wide at the end around the bearing. It will also contain four matching holes for the threaded bolt to feed through. When looking at the container from the side panel view, the side mount will be similar to a bell curve shape, with the top portion connected to the spacer ring and then to the inner ring of the bearing. The bottom of the bell curve shaped PVC will be the component that the structure will stand upon. Both sides of the mixing container will have these shaped supports. The length of each base will be 40 cm to allow for distributed loading. This feature is important as the supports keep the system upright during operation and will need to be structurally sound when the system is in operation. Each of the support edges will have a 2 cm edge, 1.27 cm tall that will be chemically bonded and flush along the side of the support. This edge will have two mounting holes to enable fastening to the flat surface beneath the structure. From the center of rotation to the flat surface will measure 30 cm, allowing for over 6.5 cm of clearance from the bottom of the container to the flat surface. On the primary side, within the inner bearing's circular area, there are three important connection points. The first is the mounting location for the fan. The second is the brass vinyl tubing connection adapter, and the third is the hole where the sensor axle will be held in place by. The secondary side, also within the inner bearing's circular area is two components. The first is the output air vent, and the second is the hole where the other end of the sensor axle will be held.

Along the center axis of the container will be a PVC tube that will contain the wiring for all six sensors. Each sensor uses three wires, so at the primary end of the PVC tube will be an 18 pin connector in which to allow a quick disconnect during maintenance or emptying material. The PVC piece is comprised of seven sections of smaller diameter tubing and three Tee fittings. Four of the smaller diameter sections and the three Tee junctions will make up the horizontal portion of the fixture. There will be one smaller diameter section followed by a Tee junction until all three Tee junctions and four smaller diameter sections have been utilized. The overall length of the horizontal axis will be 43 cm. The ends of the axis will also be threaded so that end caps can be tightened over them and keep the axle from rotating or moving when in operating mode. Stemming from each of the perpendicular PVC Tee junctions is a smaller diameter column that will contain the sensor end points. These columns will also be threaded on both ends allowing for easy installation of sensors and assembly. The temperature and humidity sensors will be held in place by an end cap at the bottom of the PVC column. This configuration will be the same for each of the three PVC columns and configuration is important as it enables a distributed measurement of the temperature and moisture in three sections of the container and gives the sensors a rigid hold while the material is being mixed and moved around their locations.

Along the horizontal segment, outside the PVC but inside the mixing container, the misting tubing will be fastened to this section. This is an advantage during times of maintenance and when the cycle of composting material begins and ends. It is also important to have the misting system separate from the sensor wires and connections to minimize any degradation of those cables and the sensor functionality. The misting system will be connected to the brass size converter that bridges the component to the primary side connections. The Hydrations System Details in section 6.5.2 includes the configuration of the misting system in section 6.5.2.4.

The entire mixing system will be mounted on a level, flat surface. The motor utilized will be located directly in front, on the same platform, of the mixing container for easy maintenance and adjustments. The motor will have a sprocket mounted on the shaft. Both the small motor sprocket and large container sprocket will utilize a chain link system that rotates the entire container from the center of the cylinder directly between the primary and secondary sides. The motor will be held in place by an acrylic frame custom fitted to the motor dimensions. This is because the mount available on the market is not durable enough for this application. The available motor mount only supports the front end of the motor on the shaft side and does not aid in resisting the turning force and strain that the chain places on the motor. Therefore, both the front and back end of the motor will have a mount that securely keeps the motor in place while in operation and idle. The chain will be able to be disconnected using a tool so that the container can be removed and emptied and refilled. The chain is designed to be able to be added after the container ingredients are added and finalized. This feature is important because if the chain was not so easily removed, it would cause many design and functional challenges throughout the entire process. The motor mount assembly will also be mounted on a sliding rack perpendicular to the longer edge of the mixing container. The rack is commonly used in sailing boat applications and is called a “Sail Track” [24]. It enables a component to slide along a rail in a linear path while the sliding component is able to be locked in place using a screw. The rail will be permanently mounted on the flat surface that the container is mounted to. This track will allow for the chain to be easily loosened and disconnected. In all, it makes the process easier and can be performed with minimal effort. When the chain needs to be reconnected, the motor is slid closer to the mixing container, and the chain connected then placed over both sprockets with ease. After both sprockets have the chain, the motor mount is slid away from the container until the chain is taught. When the motor reaches the ideal position, the locking screw is tightened and the motor is locked in position along the rail. This rail component was selected because of its design and durability for outdoor use. The materials used are anodized aluminum, stainless steel, and fitted nylon for less resistance. Both the figures below (Figure 51 and 52) represent the large chain drive and sprocket design features shown from two different vantage points. The motor is shown immediately next to the small sprocket.

The final system, shown in Figure 53, did deviate from this design, however, it did contain similar fundamentals. The outermost assembly was all acrylic and was connected utilizing the lazy susan bearings. The rotating shell had an octagonal rim which enabled four bolts to keep the outer assembly in place. The center holes were large squares due to ease of cutting and manufacturing. The motor was fixed on a piece of wood which was mounted to the base of the entire system. The legs of the mixing container held the entire assembly in a fixed position and ensured solid contact was made between the motor rotor and the circular acrylic which was essentially in place to drive rotation of the container. A connector was not used; however, the wires were extended to ensure proper connection to the PCB.

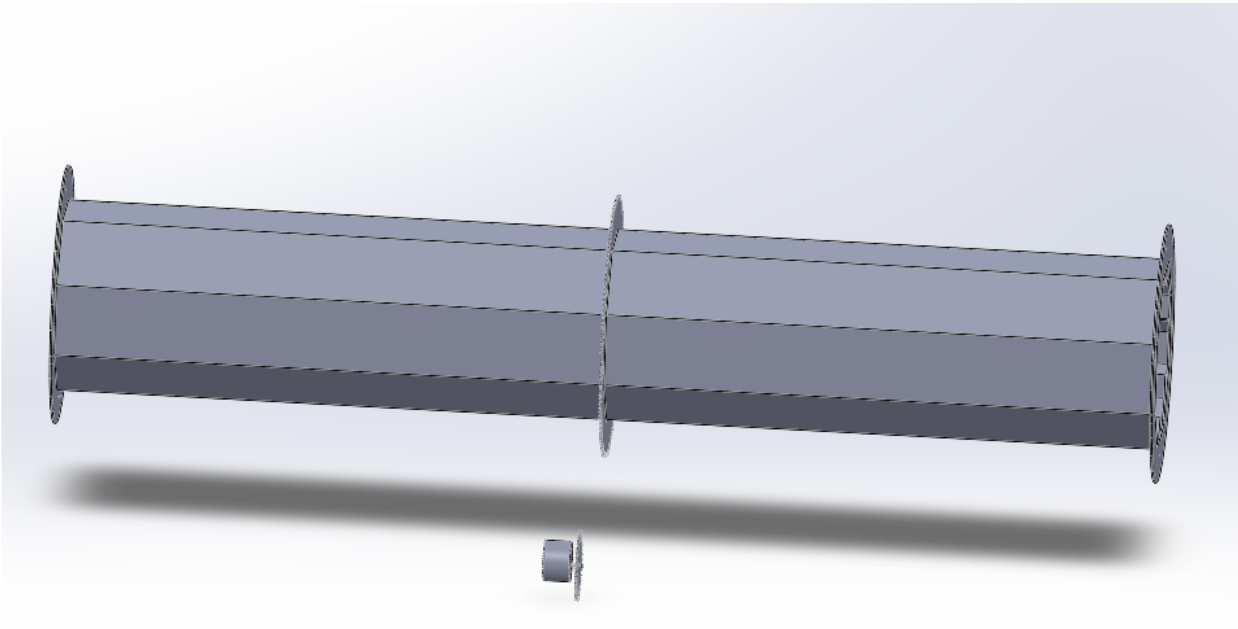

Figure 51: Mixing Container with Gear and Sprocket

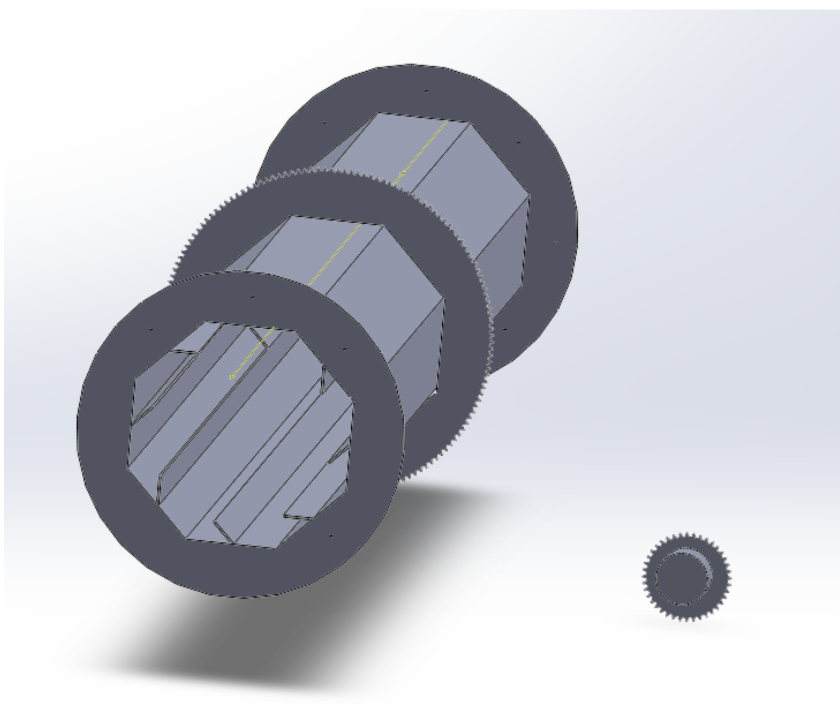

Figure 52: Mixing Container with Gear and Sprocket

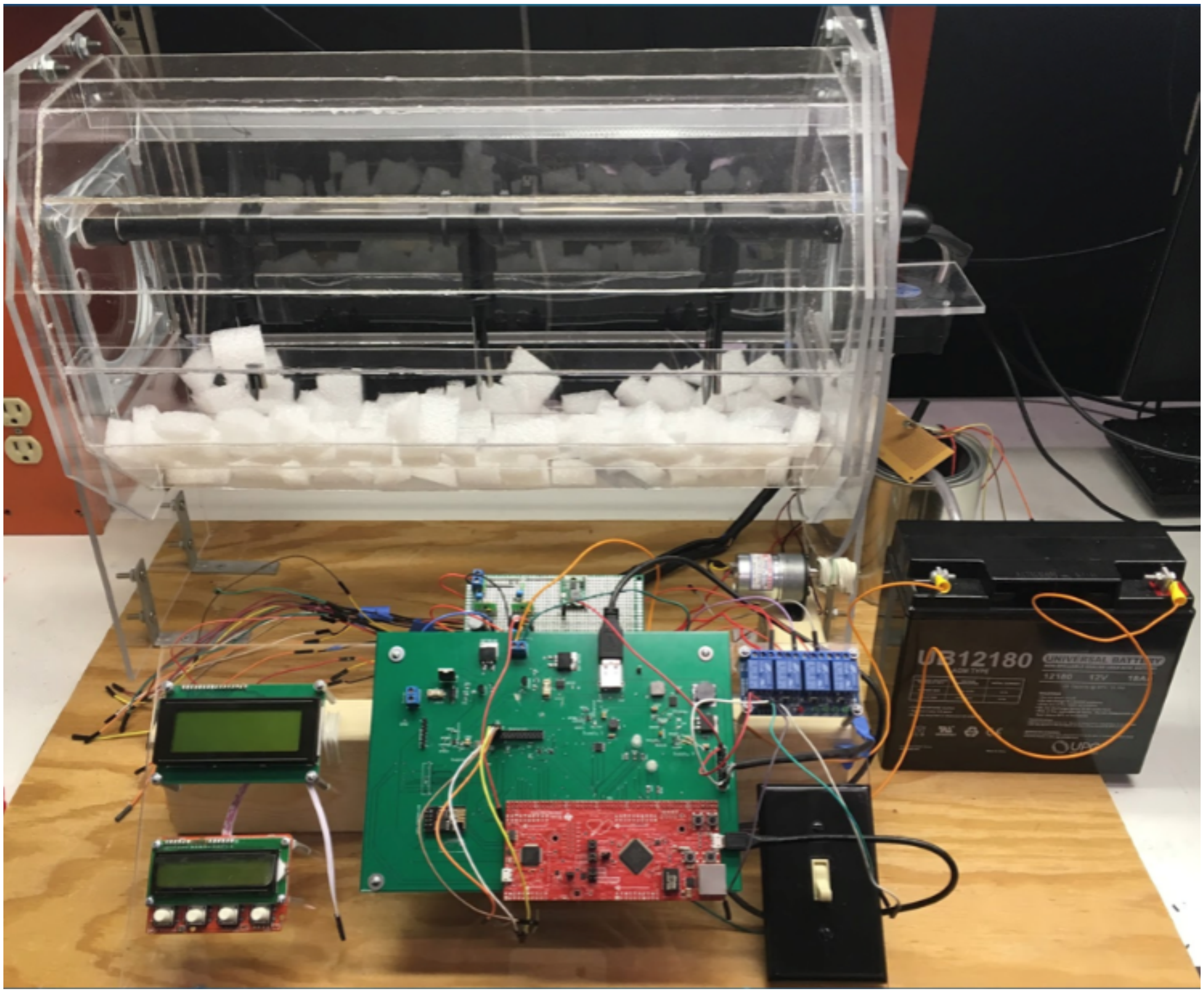

Figure 53: Complete System Product

6.5.2 Hydration System

A motive of this project is to make the system efficient and the way to do that is streamline the composting process. Compost excels in ideal moisture conditions, so the system must include a mechanism to control the moisture environment contained inside the compost bin. This branch of the system is the process that allows access of water to maintain the moisture content of the compost. It is necessary to control this important aspect of the mixture enclosure's environment in order to ensure the system's predestined plans follow through the compost material's entire life cycle. In the design of this system the goal is to transfer water from a water tank to the compost mixture. Water is an essential component of such a system in controlling the moisture content within the mixing cylinder. The hydration system will include a water container (which includes the IR water level kit), a pump, vinyl tubing, and misting components.

A four liter, polycarbonate water tank with the dimensions of 0.21x0.15x0.22 m will hold the necessary water that the system needs to maintain moisture levels. Therefore, the water tank must have the dimensions that correspond to the compost mixing bin. The water tank must also be made of durable material for outside weather conditions. The lid will be made of polycarbonate as well and will have a hole to have the vinyl tubing routed through. An additional hole for pressure equalization, and the IR water level detection hardware will be through hole mounted. Both the Vinyl tubing and IR kit will be able to be removed when the container needs to be filled. As a supporting feature to compare the water level detection level, the container includes a permanent marking system on the exterior displaying values from one liter to four liters with intervals at each whole liter. The water sensor plays an important role in the maintenance of this system. The water level detection protects the water pump from trying to operate if there is not enough water left in the tank. However, the pump will continue to operate without risk of failure if there is no water being pumped. The water level is measured using three components. First, the IR emitter will emit a frequency of 40 kHz that is directed at a floating piece of Plexiglas that is on the surface of the water. Next that signal is reflected due to the composition of the Plexiglas and is returned back to the IR receiver. From this point in time the signal is then sent back to the MCU and interpreted to reflect an accurate reading of the current water level. This operation occurs at the beginning of a composting cycle to ensure that there is enough water present to complete the cycle. If and when water is needed, the software will display the information for user to see. The water pump device is the core mechanism in this process. It pumps the water from the water tank through the tubes that lead to the compost mixture inside. When the MCU verifies that the water volume will suffice for the current low humidity level of the material, it will send a signal to the PCB which will turn on the switch that activates the pump to operate. This process will continue until the optimal humidity level is reached. The pump chosen, (Model Number: H10448), was selected based on its characteristics. It is able to be submersed due to its IP68 waterproof class. This is important because the unit is designed to be in an outdoor environment and will likely be exposed to moisture. The pump is able to pump water up to 60 degrees centigrade which is well above expected ambient water temperature within the storage container. Additionally, the pump is suitable for many types of liquids, including acidic solution so water will be unlikely to enhance degradation of the components. For maintenance and ease of installment, the pump will be mounted outside of the water container. This will enable easy installation of vinyl tubes and modification of mounting assembly. The vinyl tubes will be two 5/16” tubes connecting to both the input and output inlets. The input vinyl tubing will have one end connected to the input inlet of the pump and the other end will be positioned at the bottom of the water container to be able to receive the most amount of water possible and minimize having to refill the container at a premature time. The output vinyl tube will have one end connected to the output inlet of the pump and the other end will be connected first to a manual cutoff valve, then on to a 5/16” to 3/8” brass converter to connect to the misting portion of the moisture system. The cutoff valve is in place when detaching the vinyl tubing from the 5/16” side of the brass converter. Its primary function is utilized when the compost material is mature and the mixing container needs to be emptied. Vinyl tubing was selected due to its inexpensive yet durable functionality. In the event that the tubing wears out or needs replacement, the material is easily found online and in store. Looking at the misting system from the 3/8” side of the converter to the mixing container, there will be a screen, a check valve, and lastly four misting outlets. The check valve and screen are in place to keep the water from returning back into the tubing and debris from mixing with the material. The check valve complements the overall need for the cutoff valve stated in the Vinyl section 6.5.2.3 as it will be most important during the emptying of mature compost from the mixing container. Each of the four misting nozzles has a 0.3 millimeter opening which produces a very fine mist. This is important since it will be most effective in keeping the humidity level uniform across the compost material as the moisture is spread across a maximum surface area. As the mixing system rotates, the material will be covered with mist as it makes its way to the surface. Additionally, each nozzle will have a filter to assist in only allowing the highest quality water into the compost material. The filter will reduce scaling and reduce frequency of cleaning the interior of the mixing container. After mature material is removed and the container is set for a new load, the misting nozzles can be used to rinse the inside of the container. This is also important when the unit is not in use and needs to be cleaned and stored.

The hydrations system in the end utilized the water pump listed below in table 24. However, a standard empty paint can be utilized as the water container, thus removing the need for items 12 and 13 in table 24. Additionally, the dry box was not implemented due to the non-necessity of having the system live outside and acrylic replaced the necessity for a sheet of PVC.

Item	**Name**	**Manufacturer**	**Part #**	**Qty**	**Cost ($)**	**Total**
1	Dry Box	Sockit Box	285 BLACK	1	$15.99	**$15.99**
2	PVC Sheet	Vycom	46014	1	$102.80	**$102.80**
3	Acrylic Sheet	OPTIX	MC-100S	1	$96.00	**$96.00**
4	Lazy Susan Bearing	XMJ	XMJ006	2	$15.99	**$31.98**
5	Motor	Lynx Motion	GHM-01	1	$21.95	**$21.95**
6	PVC End Cap	Charlotte Pipe	PVC021160800HD	5	$0.53	**$2.65**
7	PVC Tubing	JM Eagle	530048	1	$2.29	**$2.29**
8	Temperature Sensors	Maxim	DS18B20	3	$2.74	**$8.22**
9	Humidity Sensors	DFRobot	SEN0193	3	$7.90	**$23.70**
10	Fan	Lonestar Idustry Group	HT07530	1	$8.95	**$8.95**
11	Roller Chain	Cadence Supply Company	RC35-1R-10FT	2	$7.56	**$15.12**
12	Water Container	Cambro	RFSCW4135	1	$14.99	**$14.99**
13	Water Container Lid	Cambro	RFS2SCPP190	1	$7.06	**$7.06**
14	IR Emitter	OPTEK TECHNOLOGY	OP295A	1	$0.71	**$0.71**
15	IR Sensor	Sharp	GP1UX51QS	1	$2.99	**$2.99**
16	Water Pump	Docooler	H10448	1	$11.99	**$11.99**
17	5/16" Vinyl Tubing	Beesclover	B000E62TCC	1	$6.25	**$6.25**
18	5/16" to 3/8" Brass Converter	Brass Fittings	UNB-6-5	1	$1.76	**$1.76**
19	Check Valve	AquascapePro	61003	1	$4.94	**$4.94**
20	Four Point Misting Assembly	Orbit	1406-8274	1	$12.64	**$12.64**
Total						**$392.98**

Table 24: Mechanical System Bill of Materials

6.5.3 Solar Rack

Florida is known for great sunshine, but even the angle of the sunlight can vastly affect the solar panel's energy absorption. In the process of mounting the solar panel to the self-sustaining mechanism, the need to optimize the solar panel's abilities must be recognized. This section highlights the different forms of solar mounting that exists and what path would be most beneficial for this project.

Solar mounts can be uniquely fitted for a variety of situations, accommodating any parameters or variables that might be encountered. The largest benefit to solar mounts is that they allow for a variety of specific tilt angles. The array can be set at an optimal tilt angle based on the system's location or repositioning to fit the location's daily or seasonal changes. The tilting leg of the mounting device used in this system, as shown in Figure 54, is manufactured to rotate to different tilt angles or with telescoping legs that have infinitely adjustable tilt-angle locking points. Since these mounts tilt the array away from the mounting surface, the backs of the modules can usually be conveniently accessed to get to the wiring, junction boxes, and grounding points, making installation and maintenance easier. The increased distance from the mounting surface also facilitates greater airflow along the back of the modules and results in a lower array of temperatures compared to the parallel-to-roof method that suffers from collected heat near the arrays that diminishes the amount of power delivered from the array.

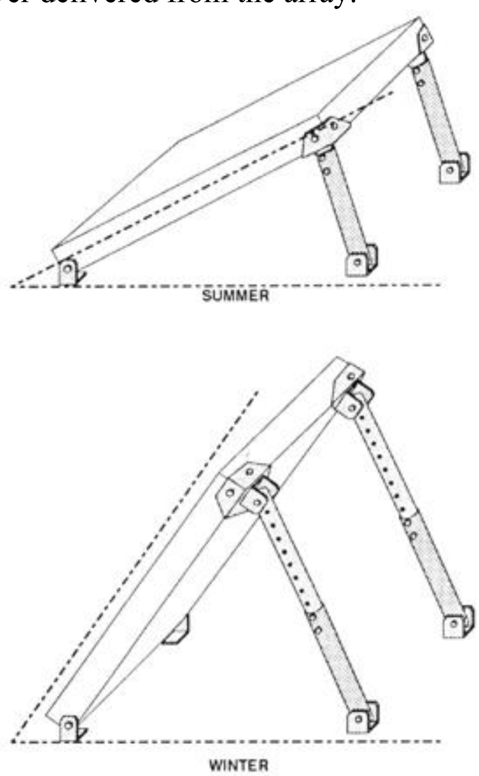

Figure 54: Ground Mount With Adjustable Tilt (Used with Permission by Affordable Solar Mounts & Co.)

The top-of-pole mounting solution is a favorite among many solar installation companies for a variety of reasons. This method has the ability to locate an array far away from shading objects, tilt and orient the array in an ideal position, and to avoid any obstructions with the structure around the array. The tilt is a mechanical design that allows full 3-directional rotation around the rotating center point. With the advent of high-voltage string inverters, and MPPT controllers that can step down higher-voltage photovoltaic arrays to a lower battery charging voltage, pole mounts can be located farther away from the charge controller or inverter. Because the array sits several feet from the ground, allowing for the greatest amount of airflow, top-of-pole mounted arrays operate at lower temperatures than roof and ground-mounted arrays. This reduces the amount of power lost when ambient temperatures are high [29]. The ability to adjust the array tilt seasonally is a natural function of any top-of-pole mount. This can be of particular interest for off-grid systems that rely on every kWh of electricity produced by their photovoltaic systems. In cold climates and areas, top-of-pole mounts are one of the most convenient racking options if snow needs to be periodically cleared from the array. Top-of-pole arrays can also be used with tracker systems to help boost photovoltaic production even more.

Due to the structure of this project, the top-of-pole mounting structure will be designed to fit this mechanism using adjustable telescoping legs and a rotating platform that allows the solar panel a full 360°. The mechanism will have a connected base platform that connects to the pole mount. The pole will connect to the array platform using a universal two-way adjustable solar panel mounting bracket as shown in Figure 55 that can be held fixed at any tilt. This feature allows the ability to optimize the array's power storage because a photovoltaic array generates the most energy when its modules are directly facing the sun.
In the final iteration of the system, there was no implementation of the solar pole mounting due to the wood base that was available for the mounting of the system. The panel could have been mounted but was not done to ease in transportation. It could have however been mounted in the way that the document details in future iterations.

Figure 55: Panel Mounting Bracket (Used with Permission by Affordable Solar Mounts & Co.)

6.5.4 Electrical System

Storage of delicate, fragile electrical devices is very important to maintain the system. This section will address the mechanical housing, storage, and electrical connections necessary to protect the electrical wires and devices in the system.

6.5.4.1 Dry-Box

A dry-box is a waterproof container that would house electronic devices that could get damaged from outdoor conditions. In the system's design, an MCU operates as the brain control center and because of its open pins and wires, requires protection from the elements and is just one of many devices that need to be housed in the dry-box. The microcontroller connects to the PCB which connects multiple devices and external parts, like switches and other electrical systems. The dry-box shall be large enough to contain of all these parts in an organized layout that allows for wired connections to the devices. Not only would the dry-box meet the physical volume parameters, but also the electrical wiring parameters. The containment center must allow the MCU to externally access and communicate with other parts of the system, like the mixing container, hydration system, and display screen. The dry-box allows for external connections using silicon seals molded around cables to seal the connections as well as a clasping lid to seal the top opening of the container. Figure 56 shows an image of how the dry box seals the cable connections using square silicon pads at the opening for each cable [30].

In the system's final design, there was no inclusion of a dry box and this was due to reduce the budget and since the system would not be permanently housed outside.

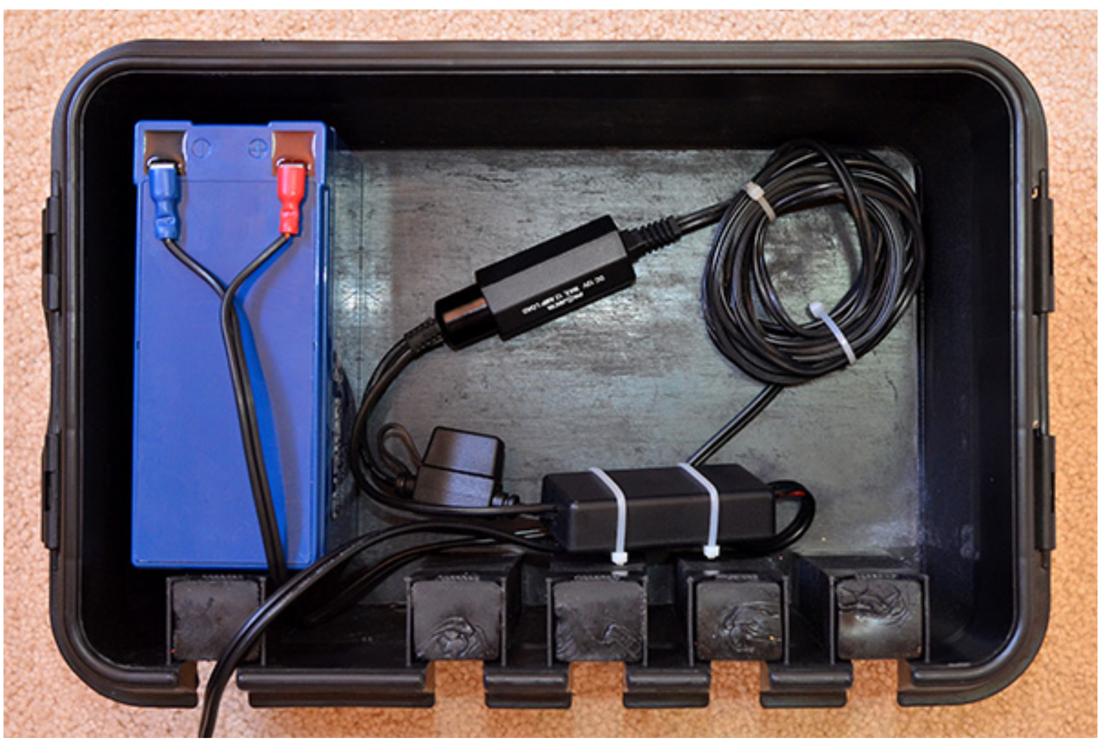

Figure 56: Dry Box with Silicon Sealed Cable Connection (Used with Permission by MCM Electronics)

6.5.4.2 PCB Mounts

The PCB is kept in the dry box for safe weatherproof conditions. The PCB will use Harwin's R30-3010502 hex spacers with a thread size of M3 and length of 5 mm. They are made out of brass with nickel plating and be used to hold the PCB in place to avoid any physical contact or harm from other components in the dry box. The mount has both, a male and female port, on either side of the part. This allows for the simple mounting by screwing the male side into the box for stability and a screw to mount the female end to the PCB.

PCB mounts were 1 7/8 inches long and had female opening on both ends. All related hardware such as the two LCD’s, PCB, relay module, and battery switch were mounted on an acrylic piece and all except the battery switch were placed on the standoffs. This change was due to availability of hardware from local stores.

7.0 Integration & Testing

This document has discussed the different subsystems (power, hydration, control, etc.) and how they are designed thus far. To bring everything together, this section shall examine the system as a whole and how the different sub-systems are integrated. Also, the testing procedures, both hardware and software, for each individual component (sensors, microcontrollers, LCD, motor, etc.) shall also be discussed.

7.1 Integration

Taking a look at a high level view of the system it is important to note that there are many different parts, each with their own myriad details that do not necessarily pertain nor affect the operation of other parts of the system. For example, there are major sections of hardware (power, embedded processors and circuitry) as well as software (cloud computing, mobile application, embedded software) that will need to be integrated. This section serves to detail how each of these parts will be brought together to form one, cohesive whole starting with system level integration and then discussing how the PCB will be utilized to achieve this integration.

7.1.1 System Integration

The composting system shall be integrated through the process of vertical integration, where the subsystems are integrated based on their unique functionality. Starting with the power subsystem, a switch will be used to connect the battery to the different hardware components in the control subsystem. When turned on, the switch completes the circuit, allowing current to flow through and power the control subsystem. This also allows for the control subsystem to power down itself through an option available on the LCD screen. A common problem when connecting power to the system is that the amount of voltage might be too low, or worse, too high for the system components. As such, extra care shall be taken to ensure that the power source will provides the appropriate voltages to match the different voltage requirements of the components. Additionally, an inspection of the switch shall be done to verify that it is operating normally before any actual connection is established between the two subsystems. When integration is done, the LCD should be on with a message confirming that the system is ready to go.

From here, the control subsystem shall be integrated with the mixing and hydration subsystem. For the mixing subsystem, the motor, fan, temperature sensors, and moisture sensors shall be wired to and controlled by the microcontroller. This allows for the microcontroller to interact with sensors' data and manage the motor and fan. After integration, the microcontroller should have the full capability to control the speed of the motor, switch the fan on and off, and perform specific actions based on the sensors' data. Similarly, for the hydration subsystem, the IR distance sensor and the water pump are to be connected to and controlled by the microcontroller. By itself, the water pump has to be manually switched on and off. Through integration with the control subsystem, the microcontroller can now determine when to switch the water pump on and off to pumps water into the misting components inside the mixing container, as well as how long to do it for. Also, the microcontroller should be able to attain information regarding the water level inside the water tank from the IR sensor.

Besides the major subsystems that were mentioned, there are also two smaller ones that are to be integrated to the control subsystem: the display and the wireless connection subsystem. Both subsystems connect to the control subsystem through their respective controllers. The controllers help to take work load off of the microcontroller as well as reduce the pins needed, offer additional functionalities, and provide interfacing between the peripherals and the microcontroller. The display subsystem consists of the LCD display, the capacitive touch panel, and their respective controllers. Integration with the display subsystem allows for the control subsystem to send system information to the display for users to view as well as receive user-inputs from the display. The wireless connection subsystem, however, only consists of the WiFi controller. Integration with this subsystem provides the microcontroller with the functionality and capability of being able to connect to the Internet for communication access to the mobile application.

There also needs to be integration done for the software/testing subsystem and the control subsystem. In order to debug and download software onto the microcontroller, a JTAG programmer with a USB port is required for interfacing between the computer and the microcontroller. The programmer can be purchased separately or found on a launchpad, the latter of which shall be used. This integration allows for the developer to download the necessary instructions for the control subsystem to effectively manage the entire system. Also, the developer can test various inputs from the microcontroller and have the outputs be printed onto a computer console.

All the previously mentioned subsystems need to be integrated with the mechanical subsystem. The entire system shall be on an elevated platform. The power subsystem shall be off on the side with the solar panels mounted onto the solar rack and the battery and charge controller located underneath. The mixing subsystem shall be placed in the middle with the motor on a mobile mount that can be moved in the direction perpendicular to the mixing container. The temperature and moisture sensors are attached inside the mixing container along with the misting components from the hydration subsystem. Thus, the hydration subsystem should be right next to the mixing container. The control subsystem shall be placed inside a water-proof cover to shield against rainy weather along with the controller parts of the wireless connection and display subsystem. However, the LCD shall be attached to the front of the entire system to allow easy access for the user.

7.1.2 PCB Fabrication

Printed circuit board (PCB) layout is an integral piece to the successful operation of this system. This piece of equipment acts as the overall transportation system for all voltages, currents and control signals. Each component within the prototype is be controlled with a signal and powered by a source that has traveled through the paths laid out on this piece of hardware. A PCB is made up of both nonconductive material and highly conductive material. For this prototype, the nonconductive material is a glass reinforced epoxy resin called FR-4 and the conductive material is copper tracing. With the combination of these two types of materials, electrons can flow only where the conductive paths allow and not cross over the nonconductive surfaces. Signals are routed on directed paths called copper traces. Depending on the requirements of the components and sources, the paths must be a certain width and the length should be minimized to reduce losses. Additionally, the proximity of one trace relative to another need to be given attention as the closer the traces are, the risk of a short increases. If there are too many components and overlapping paths that make it difficult to have a single layer board, the PCB may need to be multiple layers. For this design the goal is to keep to two layers and have clear space between copper traces. Throughout the board layout stages, the key will be to organize the connection points closely to other junctions and connected in a linear way, reducing any chance of overlap. When adding multiple layers, it adds complexity and cost. The various layers connect with pathways called vias [36]. These connecting points enable electricity to pass from one layer to the next. While these are all important considerations when it comes to PCB composition and design, the actual components cannot be ignored. Components have a life cycle and could be obsolete, out of stock, have a minimum buy quantity, and various footprint sizes. For this design, the PCB design will utilize surface mount parts. This is due to the intent to create a two-layer PCB for simplicity and reduced cost. Additionally, without a constraint on board size, additional copper pads can be added to add additional components if needed and to try a different component instead of another. Additional headers and paths are implemented as well. This type of foresight and expansion option will allow for modification to be made without the need to redesign and fabricate additional PCBs. With many variables, the parts still need to be mounted properly on the board to have a functional PCB design. Once the specific parts are selected, the PCB board design software must integrate an accurate footprint layout to ensure the proper connection is made once fabrication is completed and population of the components begins.

This board shown in Figure 57, was designed using Eagle Cad and TI software and libraries. This specific PCB design powers the system with a charge controller circuit connected to DC-DC converters that provide power to the multiple loads as seen in the top half of the board. The Tiva-C, Wi-Fi controller, and LCD connections are also connected to power sources and other devices to allow communication with the microcontroller. In total, there are 88 devices and surface mounted parts including header pin connectors. The physical layout of the board was modeled after each IC's recommended design provided in the user manual or data sheets of device components and is approximately 8.7"X6" in size. This system's board is two layers and has a 1 oz/ft2 thickness and the final design was fabricated and manufactured by PCBway.com.

Once the PCB was fully designed and fabricated, it was tested and verified that no traces are shorted and all connections are routed correctly. Since the board is a two-layer PCB, the tester would have an advantage in accurately verifying proper path connection both visually and with the use of a digital multimeter on the connectivity setting. Once all tests were completed and the PCB has been proved fully functional, the board then was clear coated to prevent damage from moisture and impurities. With two forms of verification the end user would have a greater confidence to begin populating the PCB with the components. After the board was populated and all connections verified, the board was integrated with the rest of the system. This includes the connection points to all switches, sources, sensors, and primary circuit components like inductors, resistors and IC's. After this, the PCB was ready for testing the functionality of the entire system. As discovered in testing the multiple subsystems on the board, there was an issue found in the outputted voltages of the DC-DC converter supplies. While the rest of the system proved functional, a protoboard was soldered and externally attached with wires to the sensor outputs to connect the externally designed DC-DC converter supplies.

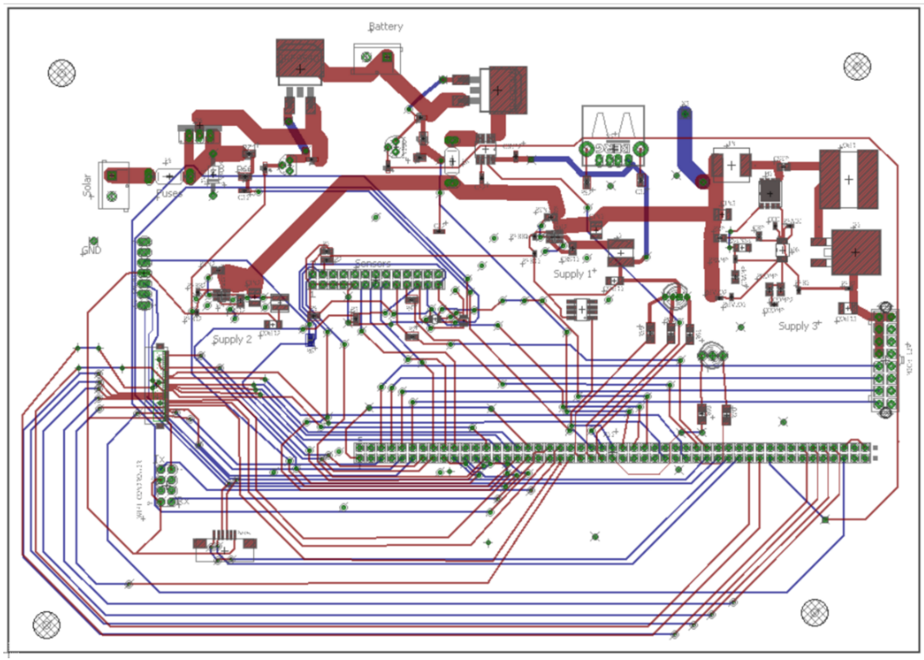

Figure 57: Automatic Aerobic Composting Machine Printed Circuit Board Design

7.2 Testing Procedures

This section goes into detail of how each part of design system will be tested before integration. Testing each part separately will reinforce confidence in its functionality and provide a fluid transition into the integration stage for system level testing.

7.2.1 Power Testing

When testing the DC-DC conversion and charge controller components, the key values to measure are voltage and current. For the all the DC-DC conversions, the voltages should be within 5% of the expected output as the WEBENCH ® design files had an output specification of maintaining within 5% of the desired output voltage ripple. As for the controller, testing will be done to ensure the proper modes of operation are executed. The modes of operation will maintain the overall health of the battery and keep it fully charged as often as the solar panel can supply the needed voltage and current. In table 25 the voltage and current tests are reviewed that will be performed for all seven DC-DC stages. For the charge controller there are three modes of charging. In Table 26 each of the three modes will be tested and verified to ensure that the charge controller functions as it is designed.

#	Description	Conditions	Expected Results
1	To ensure that all seven supply stages convert the input voltage to the seven desired output levels.	The input of each supply will be connected to a DC power supply set to the correct voltage level and the output voltage will be measured using a digital multimeter (DMM).	For each supply circuit where input voltage is supplied, the expected output voltage is within 5% of the voltage level set point as shown in 6.1.1.
2	To ensure that all seven supply stages supply the correct minimum current needed to power loads.	All loads are implemented using bread board connection to DC adjustable load across the output of the seven supplies and current drawn is measured by the DC supply connected across the input of the seven supplies.	All currents drawn from the supply meet the minimum value needed as shown in section 6.1.1.

Table 25: DC-DC Conversion Circuitry Testing

#	Description	Conditions	Expected Results
1	Verify bulk charge mode is established.	The input of the charge controller is connected to a DC power supply at a voltage of 15V and the output is a battery held at 80% of full. A current clamp is placed on the output to measure the current delivered to the battery.	The current is within 10% of the max ideal current that the panel can provide.
2	Verify absorbtion charge mode is established.	The input of the charge controller is connected to a DC power supply at a voltage of 15V and the output is a battery held at 90% of full. A current clamp is placed on the output to measure the current delivered to the battery.	The current is within the range of 0.5A-1.5A.

#	Description	Conditions	Expected Results
3	Verify float charge mode is established.	The input of the charge controller is connected to a DC power supply at a voltage of 15V and the output is a battery held at 95% of full. A current clamp is placed on the output to measure the current delivered to the battery.	The current is within the range of 0A-0.5A.

Table 26: Testing Modes of Charge Controller

7.2.2 Hardware Testing

Before the assembly phase, each part must be tested individually to confirm that they are operating normally. This section will discuss the testing procedures that will be used to evaluate the quality and performance of the hardware for the control system. This consists of the microcontroller, sensors, and display.

7.2.2.1 Microcontroller

When testing the hardware of the microcontroller, the focus should be placed on testing the connections and circuitry of the pins as well as the current consumption of the power pins. Table 27 lists the tests that will be executed to verify the functionality of the mentioned components. It is important to note that test #2 will be done simultaneously with most of the software testing procedures for the microcontroller in section 7.2.3.2.

#	Objective	Description	Conditions	Expected Results
1	To ensure that the MCU is working properly when supplied with roughly 3.3 V.	This test will involve building a simple circuit to connect a programmable LED to one of the GPIO pin on the MCU. The tester will download a simple program to switch on the LED and then connect the power source to the power pins on the MCU.	The MCU will be connected to either a computer using a USB cable or to a series of batteries. There should also be a voltage regulator to adjust the voltage level down to around 3.3 V.	The LED should light up and stay on while power is being supplied to the MCU. Vice versa, the LED should switch off when power is disconnected.
2	To ensure that every pin on the MCU that will be used is working properly.	The tester will, one at a time, connect each peripheral to its respective pin to test the connection. The digital sensor will test the UART, the analog sensor for the ADC, the motor for the PWM, and the touch panel for the I^2C on the MCU. The LED should be connected to each of the GPIO pins that are planned to be used.	The MCU should be connected to one of the analog and digital sensors that will be used, the motor, the touch panel controller, and an LED. Appropriate voltages should be applied to each peripheral's needs.	The digital and analog sensors should send data to the MCU which can be printed onto a terminal. For the motor, the tester can increase and decrease the speed of rotation. For the touch panel, the terminal should print data based on where the tester is touching the screen. And for the LED, it should simply light up.

#	Objective	Description	Conditions	Expected Results
3	To ensure that the current consumption of the power pins on the MCU match the values listed in the data sheet.	The tester will use a multimeter to measure the current traveling into the power pins on the MCU.	The MCU must be connected to a power source of roughly 3.3 V.	The tester should see that the measured current values match the ones listed in the data sheet.

Table 27: Hardware Test Procedures for Microcontroller

7.2.2.2 Sensors

This section explains the process of testing the functionality of each sensor hardware before integrating the different parts together into the system. Each type of sensor requires different hardware parts to read digital or analog signals, but will all use a breadboard to test the connections and functionality of each device.

The *DS18B20* requires integration with the MCU, but hardware testing needs a way to provide an input voltage and ground connection as well as a means of reading the output hexadecimal word that the sensor processes output. The device must be connected to the computer for testing as shown in Figure 58 using UNO R3, wires, resistors, and a breadboard. As shown, the ground, V_{dd} and data pin connect to the UNO pins respectively with a 4.7 k-ohm resistor connecting the data and V_{dd} pins [31]. Table 28 lists the tests that will be ran to determine the functionality of each component.

#	Objective	Description	Conditions	Expected Results
1	To test components and connections of the sensor.	The sensor will be placed in a controlled environment and recorded in 5°C intervals from 30°C to 70°C.	The sensor will be connected and powered through a voltage generator of 5.5 V to a breadboard the UNO board through a USB.	The sensor should output words that will correlate to a linearity with the temperature.
2	To test waterproof design and environmental functionality	Simulating the compost's environmentally damp conditions in soil and following the same testing procedure as test 1.	Testing in water or moist environment for a range of temperatures from 30°C to 70°C.	Each sensor should calibrate to output the proper range given the temperature correlation.

Table 28: Hardware Tests for Temperature Sensor

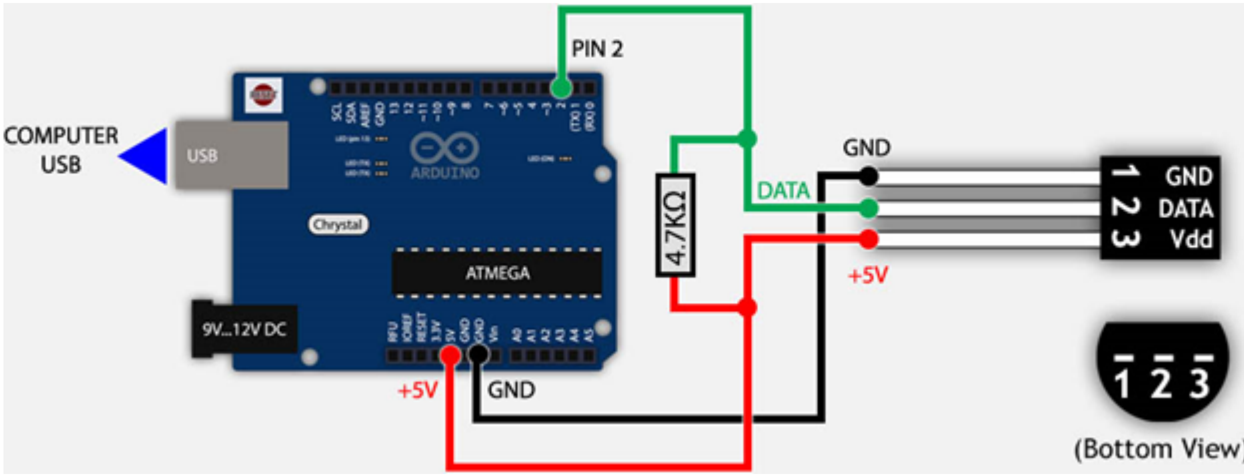

Figure 58: DS18B20 Wire Pin Interface with Arduino Board (Used with Permission by Tweaking4All)

The SEN0193 also requires integration with the MCU, but hardware testing needs a way to provide an input voltage and ground connection, as well as a means of reading the output that the sensor processes output. The SEN0193 must be connected to the Gravity I/O interface, a voltage input/ground connection, and a multi-meter to read changes in capacitance. Precautionary measures must be taken when testing because the components on this board are not waterproof, so they must not be exposed to moisture further than the red line. Components can be protected from the elements by using a length of wide heat shrink tubing around the upper-section of the board. Table 29 lists the tests that will be ran to determine the functionality of each component.

#	Objective	Description	Conditions	Expected Results
1	To test connections of the sensor.	The sensor will be provided the proper power requirements and kept in dry air, then moist soil, then water. (0% to 100% moisture)	The sensor will be connected and powered through a breadboard to a voltage source of 5.5 V and multi-meter as it encounters dry, moist, and wet soil.	The sensor and devices will output a readable signal of varying capacitance as the sensor undergoes different moisture conditions.

Table 29: Hardware Tests for Moisture Sensor

GP2Y0A41SK0F is a distance measuring sensor unit composed of an integrated combination of PSD (position sensitive detector), IR-LED (infrared emitting diode), and a signal processing circuit. The device's output voltage will be connected to an oscilloscope and a ground and voltage supply. Table 30 lists the tests that will be ran to determine the functionality of each component.

#	Objective	Description	Conditions	Expected Results
1	To test connections of the sensor.	The tester will place an object in from of the sensors receiver and measure the varying distances that the object is from the sensor compared to the outputted signal.	The sensor will be powered by a voltage generator through a breadboard to a circuit to the oscilloscope.	The voltage will change as the distance increases or decreases between the sensor and the surface.

Table 30: Hardware Tests for IR-LED Sensor

7.2.2.3 Display

When testing the hardware of the display, there are three main areas of concern: the backlight, the LCD, and the capacitive touch panel. Therefore, each one will need to undergo testing in order to determine that each one is functioning as expected. Table 31 lists the tests that will be run to determine the functionality of each component.

#	Objective	Description	Conditions	Expected Results
1	To ensure that the backlight responds to different brightness settings.	This test will involve three different brightness settings: Full-brightness, half-brightness, and off. The tester will send commands for each one and record the reactions from the backlight on the display.	The display will be connected through a breadboard to a computer through a breakout board and will be simply showing the color white.	Each setting will be registered by the backlight and will be completely white at full-brightness, half white at half-brightness, and completely black when off.
2	To test the color of the LCD.	The tester will send different color commands to the LCD, iterating through the standard 7 colors (red, orange, yellow, green, blue, indigo, and violet). Then commands will be sent for two colors and three colors to be displayed each one also iterating through the standard 7 colors.	The display will be setup as indicated in test case #1 but will be at full-brightness for correct judgement of color.	Each color command sent to the LCD will correctly show each of the 7 standard colors as indicated.
3	To test the response of the capacitive touch panel.	The touch panel will be divided into quadrants 1-4 starting from the upper right quadrant and going around in a clockwise motion. The tester will then press on the touch panel in each quadrant and record the outputted coordinates from the touch panel.	The touch panel (being part of the display) will be connected through a breakout board to a computer.	When each press is made on the capacitive touch panel, a coordinate location will correspond correctly with the quadrant that was touched.

Table 31: LCD Display Hardware Testing

7.2.3 Software Testing

This section will divulge the efforts that will be made to test all of the software components of the automatic composting machine. Major components that will have large amounts of code involved with them are the mobile application, MCU, sensors, and the display made up of also the capacitive touch panel. All testing procedures will involve computer simulations first which, once passed, will then be tested on the hardware itself.

7.2.3.1 Mobile Application

The mobile application for the automatic composting machine is the single component which contains more code than any other component of the system. This is due to the nature of the sub-components that fully comprise the mobile application sub-system: the wifi controller, cloud service, and the application itself. Therefore, testing procedures will be split up into different categories since extensive testing is needed to ensure a robust and sound mobile application. These categories are functional/usability, stress, volume, compatibility, and security.

Functional testing is meant to test the way the system is used, which is why it is often referred to as usability testing. The main goals for this type of testing is to make sure that each function of the system is operating as expected and intended. Extreme cases are not the main area of focus with this type of testing since most of the time the user will not be using the mobile application under such extreme and rare cases. Table 32 lists the planned tests that will be run to ensure that functions such as communication with the composting machine, general navigation through the application, and services through the cloud are all working as one would expect under normal conditions of usage.

#	Objective	Description	Conditions	Expected Results
1	To ensure proper navigation between different pages.	Once the mobile application is open, all navigation buttons will be pressed and it will be recorded which page/screen the tester is taken to for each button.	Normal conditions will be applied with network connections operating and device pairing having been complete.	Each navigation button will result in the display of the button's respective page.
2	To ensure commands are received and implemented from the mobile application.	The tester will press each control (Fan Control, Mist Control, and lastly the Power Control) giving a command and will record each response from the paired composting machine.	Normal conditions will be applied as described in test case #1.	Each command will be recognized by the composting machine and implemented as ordered.
3	To ensure current data is received from the composting machine.	With the mobile application open, the composting machine's sensors for temperature, humidity, water level, and battery level will be fluctuated and the tester will record when those changes occurred and if those changes were reflected on the mobile application.	Normal conditions will be applied as described in test case #1.	The current information from each sensor will be reflected appropriately on the device when each change occurs.

Table 32: Functional (Usability) Tests

Stress testing involves testing the limits of the system to see when it will break. These tests consist of extreme and/or rare cases that were not tested in the functional test cases. The main goal of these tests are to strengthen the robustness of the mobile application system so that when the user gains access to it, fewer instances of crashing and bugs are found. If done well, this type of testing can lead to fewer software updates and therefore, lead to less maintenance cost on fixing issues that may arise. Table 33 lists the planned tests that will be run to ensure that the mobile application and the cloud will react as intended under extreme and/or rare cases that may occur.

#	Objective	Description	Conditions	Expected Results
1	To ensure several subsequent commands are registered by the composting machine.	The tester will send several commands to the composting machine in rapid succession using the control buttons discussed. Each instance of a command will be recorded as well as the composting machine's reactions to the commands.	Normal conditions will be applied with network connections operating and device pairing having been complete.	Each command will be implemented correctly by the composting machine as directed by the tester
2	To ensure several page navigations are registered by the mobile software.	The tester will press a navigation button and then immediately press the navigation button to return to the original page. This will be repeated for each navigation control in rapid succession with each event being recorded.	Normal conditions will be applied as described in test case #1.	The mobile application will respond in a quick manner to each new navigation button press and will not stall.

Table 33: Stress Tests

Volume testing consists of using large amounts of connections. Since the automatic composting machine and the mobile application will be connecting to Microsoft Azure's cloud service, it will be very possible that on a large scale hundreds or thousands of iOS devices and composting machines will be sending messages and accessing the cloud and communicating with their respective paired devices. The main goal of volume testing is to ensure that the mobile application will still operate properly when large amounts of users are accessing the cloud and that it responds as intended to give the user the best experience possible. One test case will be run where multiple iOS devices will be connected to simulated composting machines setup on Microsoft Azure's cloud service. The conditions will be the same for each device where they will be connected to the same network yet each device will be connected to a different composting machine simulator in the cloud. All of the functional and stress tests will be run on these devices at the same time and operations to the composting machines will be observed and recorded. It is expected that all tests will pass both the functional and stress categories while the intended and correct changes will be reflected in the cloud.

Compatibility testing will be important for the mobile application system since there are numerous iOS devices that the application can run on. The main goal, therefore, is to ensure that on each device, the same level of quality is experienced by the user. For this category of testing only one test is truly necessary and thus will be described here. The objective of the compatibility test is to ensure a great user experience on the various iOS devices that Apple sells today: iPhones, iPads, and iPod Touches. In order to get the best range of devices two iPhones will be used (one with a 4.7-inch screen size and another with a 4-inch screen size), two iPads will be used (one with a 9.7-

inch screen size and another with a 7.9-inch screen size), and one iPod Touch will be used with a 4-inch screen size. The conditions across all these devices will be the same by doing a full reboot, connecting them to the same network, pairing them to the same composting machine, and running the same usability tests described already. It is expected that each device will function and respond as intended, the different screen sizes will not affect the layout of the user interface, and the timing of each device will be approximately the same.

Security testing will be one of the most important categories of tests that will need to be run. As the name implies, this type of testing is to ensure that the software can fend off against unwanted attacks and hackers while also reporting any such attempts to the user and to the developers. Table 34 lists the tests that will be run in order to make sure that pairing the application with the composting machine is secure, sending commands to a user's composting machine is secure, and information that is sent to the user's application is validated to have originated from their own composting machine.

#	Objective	Description	Conditions	Expected Results
1	To ensure that device pairing connects between the specified composting machine.	The tester will use multiple iOS devices and go through the pairing process with a single composting machine and record whether or not prompts are used for the composting machine's ID. The same will be tested with multiple composting machines.	Each device and composting machine will be connected through the same network and/or be simulated through the cloud.	During each pairing process the tester will be prompted for verification of the correct composting machine.
2	To ensure that security measures are functional when opening the application.	The tester will try three instances of opening the mobile application: One where Touch ID is used to verify the user, one where a passcode is used, and one when this security measure has been turned off.	Normal conditions will be applied with network connections operating and device pairing having been complete.	The tester will only gain access when the correct fingerprint is applied, the correct passcode entered, or when the feature is turned off.

Table 34: Security Tests

7.2.3.2 Microcontroller

The microcontroller is the main control for the rest of the components in the system. Thus, it will require a large amount of code to manage the different sensors' data and instruct the peripherals to perform certain actions based on the data as well as sending that data to the mobile application and LCD. The microcontroller will also have to do the same with user inputs. Table 35 presents a list of testing procedures that will be executed to verify that the microcontroller is accurately receiving data and outputting the appropriate response. As noted before, most of these tests will overlap with test #2 in section 7.2.3.1.

#	Objective	Description	Conditions	Expected Results
1	To ensure that the MCU is receiving data from the temperature, moisture, and IR sensors.	The tester needs to connect the sensors to the MCU, building any circuitry that is required to connect the sensors correctly. The tester will then continuously print the data as well as any simple message using if-else statements. For example, if the temperature is above 25 ^{o}C, then the tester should print the degree and the message saying that it is hot. Note: This test can be done with one type of sensor at a time to avoid printing out too much information at once.	All sensors that will be used must be connected to the MCU.	The terminal screen should continuously output sensor data, as well as the tester's conditional messages.
2	To ensure that the MCU is properly controlling the speed of the motor.	The tester will increase the rotation speed of the motor at five second intervals. This should be done three times and then the tester can drop the rotation speed back down to 0 RPM.	The motor must be connected to the MCU through the PWM.	The tester should see that the motor is increasing its speed at five-second intervals. After three iterations, the tester should then see the motor slow down to a stop.
3	To ensure that the MCU is properly writing to and accessing the memory buffer.	The tester will write values to memory, then attempts to read them from memory and compare the values.	The values must be in binary. Also, the tester must perform this test multiple times to cover for all the different patterns of 0's and 1's.	The tester should see that the binary values are being printed out in the correct format and that it matches te pattern of the values inputted.

Table 35: Software Test Procedures for Microcontroller

7.2.3.3 Sensors

Software testing of the sensors requires connections to the MCU and other interfacing parts to test that the program can read the correct sensing measurements.

Using Arduino IDE software, the code must be accurately adjusted to address which pins on the microcontroller are connected to the sensors. Knowing what temperature environment the sensor is in, the sensor's accuracy can be tested by getting readings from the program and comparing the results to the known environment. First test each sensor individually, then multiple in parallel on the 1-wire interface. Table 36 lists the tests that will be ran to determine the functionality of the software.

#	Objective	Description	Conditions	Expected Results
1	To ensure that the MCU is compatible and responds to the sensor.	The sensor will undergo the same test 1 from table 28.	The sensor will be connected through a breadboard to a MCU and sensors will undergo varying temperatures from 30°C to 70°C.	The MCU should read each sensor's outputs and should calibrate to read properly correlating words to the temperature range.
2	To ensure that multiple sensors can be read on the same one-wire interface	Multiple sensors are connected on the 1-wire interface and monitored as it encounters the same test 1 from table 28.	The sensors will be connected through a breadboard to a MCU and sensors will undergo varying temperatures from 30°C to 70°C.	The MCU should read each sensor's outputs and should calibrate to read properly correlating words to the temperature range.

Table 36: Software Tests for Temperature Sensor

The sensor connects to the UNO board, as shown in Figure 59, and interfaces to integrate into the MCU's program system. To calibrate the sensor, first the program must open the serial port monitor and set the baud rate to 9600. Record the sensor value when the probe is exposed to the air as "Value 1". This is the boundary value of dry soil "Humidity: 0%RH." Take a cup of water and insert the probe into it no further than the red warning line. Record the sensor value when the probe is exposed to the water as "Value 2". This is the boundary value of moist soil "Humidity: 100%RH." The final output value is affected by probe insertion depth and how tight the soil packed around it is. We regard "value_1" as dry soil and "value_2" as soaked soil. This is the sensor detection range that can be divided into three sections: dry, wet, and water. In analyzing the testing data, there should be an inverse ratio between the sensor output value and soil moisture.

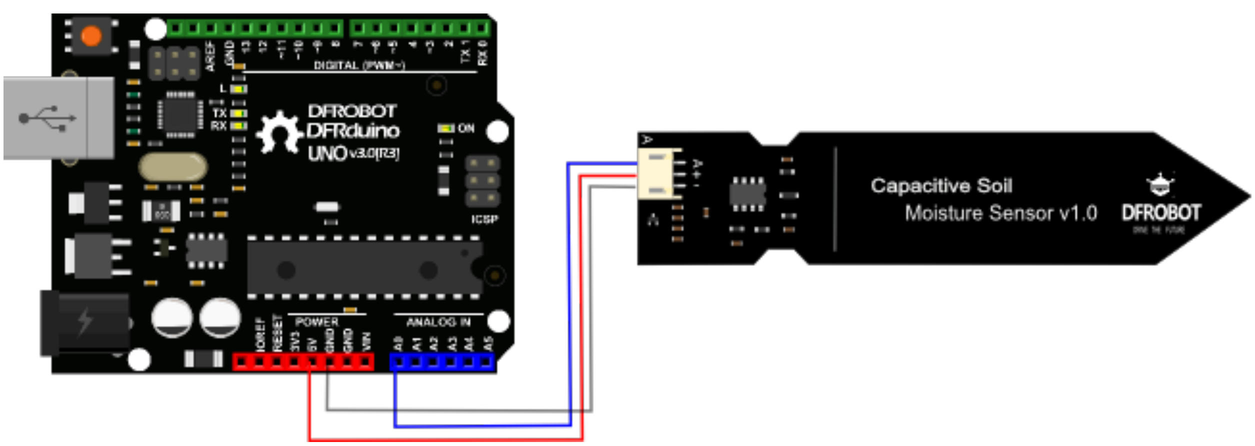

Figure 59: Moisture Sensor Wire Pin Interface with UNO Board (Used with Permission by Tweaking4All)

The program code must be accurately adjusted to address which pins on the microcontroller are connected to the sensors as shown in Figure 60. The calibrated readings of the voltages can be matched to a range of distances by testing the sensor. To calibrate the sensor, record the values of the output as a surface or material is physically in front of the sensor. For a distance measuring range of 4 to 30 cm, measure the output voltage at varying distances to find the correlation.

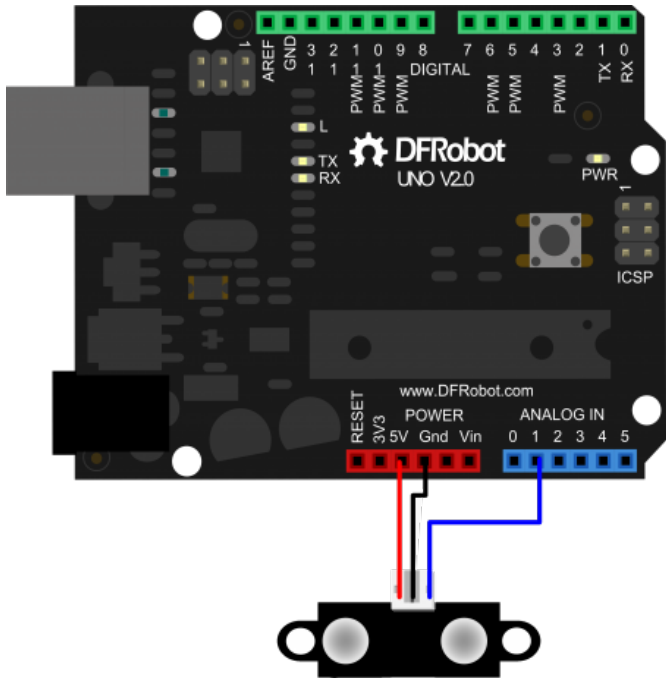

Figure 60: IR-LED Sensor Wire Pin Interface with UNO Board (Used with Permission by Tweaking4All)

7.2.3.4 Display

Testing software for the display will consist of two main aspects: capacitive touch panel input and security. The display should respond to the input correctly much the same way the mobile application should respond (navigation, controls, etc.). It should also implement the security feature of having to enter a passcode before input is received as discussed in section 6.4.2.2. Table 37 lists the tests that will run to verify that the software developed for the display is functioning as intended.

#	Objective	Description	Conditions	Expected Results
1	To ensure that input from the touch panel is registered and reflected on the display.	The tester will press each navigation control making sure to view every single page that is available and record the pages that are presented for each navigation input.	The display will be connected to the MCU through the LCD interface controller.	Each navigation command will cause the display to present the correct page to the tester.
2	To ensure that a passcode security measure is implemented.	The tester will setup a passcode on the display and then wake the display which will then prompt the tester for the passcode. At least five intentionally wrong attempts will be tested with one final correct attempt to unlock the display for input.	The display will be connected to the MCU through the LCD interface controller.	Each failed attempt at unlocking the display will result in the display still being locked while the correct attempt will unlock the display and present the home screen to the tester.

Table 37: LCD Display Software Tests

7.2.4 Mechanical Testing
This section explains the testing necessary for each part to check for its functionality, compatibility and connections with other parts. The specific parts that need separate testing are the mechanical devices that the MCU controls to integrate different factors into the compost system. The fan used for aeration, the motor for mechanical mixing rotation to also aerate the compost, and the water pump to transport moisture into the chamber.

7.2.4.1 Fan
Initial testing on the fan will be conducted to verify that the part is functioning properly and the logic from the controller is working as intended. The fan functions through a switch that turns it on or off. Table 38 lists the tests that will be ran to determine the functionality of the fan and its software.

#	Objective	Description	Conditions	Expected Results
1	To test components of the fan.	The tester will supply the fan 12dcv from a voltage generator and see if the fan rotates.	The proper power functions of 12 dcv will be connected by a voltage generator for the fan to turn on.	The fan will spin and create air flow.
2	To ensure that the MCU is compatible and controls the fan properly.	The tester will run the MCU program that commands the switch to turn on or off.	The MCU will connect to a switch that connects to the fan to command it when to turn on or off.	The fan will spin and create air flow when the switch is turned on and stop when turned off.

Table 38: Testing Procedure for Fan

7.2.4.2 Water Pump
Initial testing on the water pump will be conducted to verify that the part is functioning properly and the logic from the controller is working as intended. The water pump functions through a switch that turns it on or off. Table 39 lists the tests that will be ran to determine the functionality of the water pump and its software.

#	Objective	Description	Conditions	Expected Results
1	To test components of the water pump.	The tester will supply the fan 12dcv from a voltage generator and see if the water pump circulates the water through the device.	The inlet nozzle will be in the water so the water pump can function and the proper power functions of 12dcv will be connected by a voltage generator for the water pump to turn on.	Water will pump in through the inlet and out of the outlet nozzle.
2	To ensure that the MCU is compatible and controls the water pump properly.	The tester will run the MCU program that commands the switch to turn on and then again to turn off.	The inlet nozzle will be in the water so the water pump can function when the MCU turns the switch on to supply 12 dcv power.	Water will pump out of the outlet nozzle when the switch is commanded to turn on and stop when commanded to turn off.

Table 39: Testing Procedure for Water Pump

7.4.2.3 Motor

Initial testing will be done with a gear head DC motor. This will verify that the part is functioning properly and the logic from the controller is working as intended. A probe will be used to measure how much current is passing through the motor and what the correlating rpm is. Table 40 lists the tests that will be ran to determine the functionality of the motor and its software.

#	Objective	Description	Conditions	Expected Results
1	To test components of the motor.	Varying voltages in intervals of 1 dcv from 0 to 12 dcv will be sent through the motor to vary the rate of the motor's rpm.	Motor will be connected to a breadboard and supplied power of 12 dcv by a voltage generator.	The motor's shaft is expected to rotate at 200 rpm.
2	To ensure that the MCU is compatible and controls the motor properly.	Varying voltages in intervals of 1 dcv from 0 to 12 dcv will be sent through the motor to vary the rate of the motor's rpm.	Motor will be connected to a breadboard and supplied power by the MCU.	The motor's shaft is expected to rotate at a correlating factor between inputted voltage and rpm.

Table 40: Testing Procedure for Motor

8.0 Project Operation

The AACM is a mechanism that converts food waste into usable, mineral rich compost material. It is designed to endure outdoor conditions and any fragile parts that could possibly deteriorate are already protected and sealed off in a dry receptacle or other containment device. While the mechanism is designed for ordinary outside conditions, extreme weather may cause damage and it is necessary that the mechanism be stored in a safer, sheltered location. Normal location conditions are contingent on access to direct sunlight in order for the system to be self-sustaining. The mechanism will have Wi-Fi connection and a compatible mobile app for the user to monitor the status of the compost process while physically being far away from the device. The user will download the AACM application to their phone, connect the system to Wi-Fi network, and then check the app for system status to be "Ready" or "Connected". From this application, the user has access to the system's interface and modes of interaction. As for the process of initiating the system's composting process, there are three main avenues the user can direct the system to follow.

The mechanism allows for an easy, straightforward set of options and customizations for controlling what kind of compost the device outputs. The interface of the system gives options for multiple composting operations as well as a maintenance procedure in the operational settings. For normal system operational usage, the user will turn on the system by pressing the power button first. Then, the user has access to the home screen and can select which mode they want the mechanism to operate under. There shall be three available choices for the machine to run: automatic, manual, and maintenance. The automatic mode is preprogrammed for the system to run based on predetermined composting standards researched for this device until the compost is ready. The system will be set to maintain moisture levels of 50% to 60% and a temperature range of 40°C to 70°C. The manual setting is for advanced users because it allows users to customize run time and compost process factors, such as temperature and moisture settings, throughout the entirety of the compost's development. For both automatic and manual settings, there will be recorded history of the composting process so the user can see the mechanism's functions and readings.

After selecting what form of operation the machine will run, the user will input the necessary materials into the mixing chamber, given it is not the maintenance setting. They shall follow the suggested materials for what material to input and how much of each, typically a 30:1 carbon to nitrogen ratio. Organic material and food waste mixed with yard waste can be used as the carbon and nitrogen material. The maximum material allowable in the mechanism to function properly will be signified by the fill line or dotted line in the mixing container. Finally, given that all the maintenance features are properly accounted for, the user selects "Run" and the machine will commence with the composting process. The third mode of operation is the maintenance procedure that allows for the cleaning process of the inside of the compost machine's mixing bin. The maintenance operation is the cleaning process that should be ran after every composting process use in order to keep the system functioning properly for a longer period of time. In this mode, the system runs the motor at high rpm and the water pump at maximum water output to rinse container with a user inputted cleaning liquid. After the mechanism finishes the rinsing cycle of the mixing container, the system continues to rotate, but also initiates the fan to aerate and dry the inside.

Throughout the machine's processes, the status of the compost material can be monitored via the display or mobile app. The mobile application and display interface requires a login user ID and password to have and protect access to the system's functions and records. The layout of the interface provides access to all of the system’s features, temperature and moisture readings, water level in the reservoir tank, battery power level, power controls, fan controls, mist controls, recorded history, and settings. The temperature, moisture, and water level links all show the current respective values in the containers. The battery level shows the percentage and battery usage that the system is currently undergoing. The power control button provides the user with the ability to turn on or off the machine from within the mobile application. The fan control monitors the functionality of the fan and rate of air flow into the chamber and similarly, the mist control shows the rate of water being deposited into the system. The recorded history allows for analysis of the system's readings of temperature and moisture measurements that the current compost material has undergone. On the subject of system functions, specifications are available for monitoring different controls, status alerts and process estimates to further analyze the development of the compost. If issues arise in the system's process, a notification will appear on the display and mobile app. The user will be alerted of the problem and the system will suspend the process to avoid any damages. Details about the manner of the issue will be located in the status/alerts link on the interface. For any of the operation settings, there is an automatic shutoff switch for emergency shutdowns or to pause the system's current operations.

9.0 Administrative Content

This section serves to present a high level view of the plans this project has focused on. Two important aspects have helped to drive this system towards a prototype: milestones and budget. The milestones set forth were split into two halves: one for Senior Design I and one for Senior Design II. These will be furthered determined and solidified as the project presses forward into Senior Design II. Efforts will also be taken to reduce the budget for the prototype to be built so that the case for an affordable, automatic, composting machine can be made with confidence.

9.1 Milestones

The AACM project was split into critical milestones, each reflecting a major part of the design process that will guide the project to its next goal. These milestones give a target window for completion and also show interdependencies between different parts of the design. For instance, if the PCB board for the base station is not finished, the next step of sending it off for manufacturing will be delayed with every day. This will push every dependent milestone back causing a project delay. Table 41 is used to keep the system goals in check to reach the final goal of presentation to all of UCF's CECS department.

Name	Finish	% Complete
All Hardware/Parts Selected	2/8/16	100%
TOC Complete	2/28/16	100%
All Subsystems Designed	3/28/16	100%
SD1 Report First Draft Complete	3/31/16	100%
SD1 Report Final Draft Complete	4/24/16	100%
SD1 Report Finalized	4/27/16	100%
First Prototype Built	7/22/16	100%
Mobile App Developed	9/16/16	100%
Software Integration Complete	9/19/16	100%
Integration & Testing Complete	9/20/16	100%
Critical Design Review	9/30/16	100%
Senior Design Showcase	12/2/16	100%
Website Developed	12/5/16	100%

Table 41: Senior Design Milestones

9.2 Budget Analysis

To consider the entirety of the system, Table 42 summarizes the expenses of each sub system. The final line item of PCB fabrication estimate is included to enable a rough idea for what the actual final PCB will come out to be. As the schematics are utilized to design the PCB board layouts, a more specific cost will be identified. For the other subsections, the complete bill of materials is found in their respective sections (6.1, 6.2, 6.3.1, 6.3.2, and 6.5). Considering the nature of this design, it is expected that the power and mechanical sub systems would be the greatest cost. A standalone system must be robust and capable of independently powering itself. The mechanical sub system is inflated primarily due to the intent of the application. For demonstration and presentation purposes, acrylic was utilized. By using acrylic (a higher cost material), the viewers would be able to see into the container and witness the mounting of the sensors and hydration system. Through this visual aid, the entire systems operations can be explained without the need to imagine what's going on within the container. Because of this, the added cost of acrylic is deemed an investment rather than a wasted expense. As for the power sub system, the components selected would be able to supply power for an extended period of time. This would make the design able to remain independent of the main grid. If needed, the power system scale could be reduced to save more money yet continue to enable functionality for demonstrations and presentations. The reduced size would limit its application in the real world. Overall this budget analysis may vary due to fluctuations in price over time and the end supplier in which the components are purchased from.

Sub-System	Cost
Power Sub System	$235.67
Display	$9.65
Mobile Application	$23.23
Mechanical Sub System	$392.98
MCU	$16.98
PCB Estimate	$75.00
Total	**$753.51**

Table 42: Cost for Overall Prototype Creation

10.0 Appendices

This section is used to show the bibliography containing all material referenced within this document as well as the emails that were obtained to prove permission was indeed granted to use the figures as labeled throughout this document.

10.1 Bibliography

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10.2 Permissions

This section contains all emails and material that prove permission was indeed granted for the use of the figures and tables used in this document.

From: techsupport@maximintegrated.com <techsupport@maximintegrated.com>
Sent: Monday, March 21, 2016 6:49 PM
To: Minh Thong Phan
Subject: Copy and Usage of Photos [ref:_00D306AVj._50040uq7cX:ref]

Hi, Thomas:

There is generally no issue for a customer to use our reference design, app notes, tutorials or data sheets for their end product, including school projects.   However, Maxim does have a policy that the customer sign our Permission to Reprint document before reprinting. Then just go ahead with your project.

Below is a link to that document:

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Please sign and return to the email address listed at the bottom of this document.

Regards,
Therese Montgomery
Applications Engineering

ref:_00D306AVj._50040uq7cX:ref

Magnus Wesslén - Joraform Kompost AB April 18, 2016 at 9:37 AM
To: Cody Baker
SV: Permission to use Website Images

Dear Cody,

Thank you for your e-mail.
Yes, please use our images.
If you can e-mail me your final report I would be grateful.

Med vänliga hälsningar/Best Regards
Magnus Wesslén
Managing Director
Joraform AB
www.joraform.se
Direct phone +46 723 614453

From: support@ti.com <support@ti.com>
Sent: Monday, February 29, 2016 10:32 AM
To: Minh Thong Phan
Subject: RE: GEN, Email Technical Support, www.ti.com, TM4C129DNCPDT

Hello Thomas,

Thank you for contacting Texas Instruments Customer Support. Your email has been received and a Service Request# 1-2057302855 has been assigned to your inquiry. Please refer to the TERM of Use: http://www.ti.com/corp/docs/legal/termsofuse.shtml

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Regards,
Oslyn Baker
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512-434-1560

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From: Shayna Brock <shaynabrock@knights.ucf.edu>
Sent: Thursday, February 11, 2016 11:26 AM
To: AlexCurtiss@tweaking4allcom
Subject: Re: Permission to use copyrighted images

Shayna,

Feel free to use our images and diagrams of our devices including the infrared and ultrasonic sensors for your report. Thank you for asking and good luck!

Sincerely,
Alex Curtiss, President & CEO
Engineered Plastic Products Corporation
Elk Grove Village, IL

From: Shayna Brock <shaynabrock@knights.ucf.edu>
Sent: Wednesday, March 9, 2016 3:20 PM
To: ChristopherE@sharpsec.com
Subject: Re: Permission to use copyrighted images

Hi Shayna,
Yes, you have our permission to use the images of the GP2Y0A41SK0F IR sensor from the data sheet you requested. Good luck with your project.

Sincerely,
Emily Christopher
Sharp Electronics Corporation
201-529-8659

From: Shayna Brock <shaynabrock@knights.ucf.edu>
Sent: Sunday, March 6, 2016 11:50 AM
To: digital-innovations@ieee.org
Subject: Re: Permission to use copyrighted images

Hi Shayna,

Thank you for asking permission from IEEE for your report. Yes, you may use our diagrams that show the dimensions and charted standards for roller chains no 35.

Sincerely,
Greg Holland
Digital Innovations Team

From: Shayna Brock <shaynabrock@knights.ucf.edu>
Sent: Friday, March 11, 2016 8:26 PM
To: customerservice@tweaking4allcom
Subject: Re: Permission to use copyrighted images

Dear Shayna,
Yes, you may use our diagram images for Arduino connections with all three sensors you referred to.

Sincerely,
Richard Kaiser

From: Shayna Brock <shaynabrock@knights.ucf.edu>
Sent: Wednesday, March 23, 2016 4:30 PM
To: customerservice@affordablesolarmounts.com
Subject: Re: Permission to use copyrighted images

Hello Shayna,
Thank you for asking for our permission. You have our permission and may use the images of the adjustable solar mounts and two-way solar mount bracket.

Sincerely,
Affordable Solar Mounts & Co.

From: Shayna Brock <shaynabrock@knights.ucf.edu>
Sent: Thursday, March 31, 2016 6:18 PM
To: tech@mcmelectronics.com
Subject: Re: Permission to use copyrighted images

Dear Shayna,
Of course, you may use our images of our 285 outdoor cable connection dry box. Good luck with your project!

Sincerely,
Phil Minix
President and General Manager