Plant Automated Sustainable System (PASS)

EEL 4915L: Senior Design 2
Group #31

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1 Executive Summary

The Plant Autonomous Sustainable System (PASS) is an autonomous system that facilitates plant growth by regulating growing conditions when factors in the plant's environment change, thus curtailing the need for human intervention while increasing efficiency. It represents a proof of concept device that serves multiple objectives; sustainability, convenience and efficiency. The intended beneficiaries of this device range from the hobbyist gardener to the professional botanist and potentially, the professional farmer. To the average consumer who approaches gardening as a hobby but lacks the time needed to devote to such cultivation, the PASS offers a convenient, expedient solution. The autonomous function of the PASS reduces the amount of time a person must spend checking and maintaining their plants. The PASS may be scaled up for the needs of the professional botanist, as some nurseries are so large that the labor required to monitor the state of the plants becomes an issue. The device may reduce labor and introduce a considerable amount of convenience. Likewise, in a similar fashion, the PASS may also serve agrarian applications. The PASS offers many features; however, the primary benefit this device offers is sustainability. Plants require energy and resources for proper growth; inputs such as water and fertilizer are increasingly becoming scarce. The PASS regulates the release of such resources on a needed basis, bolstering efficiency, reducing waste and its carbon footprint.

The device is analogous to a control system; it regulates the current ambient condition of the plants environment and takes action to maintain the current state of the plant when factors in the environment change (a disturbance). The device consists of an integrated feedback network to sense environmental conditions such as light, moisture, temperature, the alkalinity of soil and other factors that govern growth. This information is sent to a microprocessor that may activate a sub-system to compensate for the ambient change. Such autonomy reduces the need for human intervention while minimizing its own carbon footprint by utilizing natural resources, such as solar energy for power. The system contains a reservoir for and an irrigation system to water the plant. Because of its inherent autonomy, the system possesses a significant feature which similar devices often lack, which is its adaptable functionality – the user may simply press a few buttons to alter the growing conditions for different plants. This is accomplished through an onboard database that contains the growing specifications for different plants. The user may wirelessly receive status updates and alerts regarding the condition of the plant via a local area network.

We have demonstrated the technical feasibility of this device and its intended merits. To that end, proper component selection, effective integration and comprehensive overall design are critical to achieving this. In addition to adequate power distribution and network architecture, obtaining accurate sensor readings and programming the controller to properly interpret that information is our primary technical goal. We intend to integrate these design aspects seamlessly to meet the requirements of the project. Technical constraints, cost

effective solutions and even aesthetics influence our component selection. The scope of this project is aimed at the average hobbyist; however, we intend to show that its functionalities may be expanded for more sophisticated, professional applications. No matter the application, our greater aspiration is for this project to offer a sustainable solution to plant growth and cultivation.

2 Product Description

This plant enclosure system provides an automated plant growth environment using power resources generated from the sun. A "state of the art" microcontroller device operates a variety of sensors, along with a watering system, and a grow light assembly. The watering systems use a robust pumping system, which waters the plant only when the moisture sensors provide an indication that the plant moisture conditions are low. The grow light assembly is used according to a pre-determined schedule in order to accelerate plant growth. The scope of this operation is the use of tropical or sub-tropical plants in order to achieve successful use of this device. Power is provided by battery via solar power charging, with commercial power used as a backup source. Overall, the PASS is a cost effective, energy efficient, autonomous system to enhance the user's ability to maintain plant life.

2.1 Motivation

Over the past couple of decades, automation has evolved in industry and society. Whether it is used for manufacturing machinery or in-door home maintenance, automation is emerging as a vital component to improving our way of life. A call for plant growth automation can provide individuals with items that they may be unable to purchase or maintain. There are some individuals who lack the "green thumb" gene and there are others who don't have enough time to care for their personal garden. A system that combines the convenience and assistance of automation with the portability of a pot is the Plant Autonomous Sustainable System (PASS).

The main motivation for a system with these characteristics is to empower those individuals who may not have the resources that are needed to have green plant life around them. A potential customer could be an individual with a busy full time schedule but the self-reliance to enjoy cooking with fresh herbs and the convenience of having their own garden. The time and resources dedicated to caring for those herbs may not be available from the client, but with an independent plant maintenance device, like PASS, it can still be possible for individuals to have their own herb garden. In summary this product provides an autonomous solution to improve the overall success of maintaining small plants. Therefore the minimum user interaction of this device can apply for personal or commercial application.

2.2 Project Objectives

The design and creation of this project using a set of goals to improve success and produce a sufficient prototype. The following objectives highlight the primary goals.

- *Portability* – The overall size and weight of the device has been optimized to ensure portability. This allows for a wide range of users since there is a minimal user physical burden.
- *Renewable Energy* – The main source of energy for the system is via sustainable energy, such as solar power. Power management is important to consider during the design process and techniques such as sleep cycles and minimal power usage have been considered.
- *Usability* – An ergonomic design is a main focus for this system. User interaction is implemented through graphical user interfaces that are easy to learn and use. The system provides the user with multiple options to interface with PASS such as through a handheld device like a smart phone or tablet.
- *Sustainability* – The system is able to operate with minimal user interaction and it shall be self-monitoring. If any critical system errors arise, then the user is notified for support. Arrays of sensors are used to keep the system updated on the overall plant health and to report results to the user. Overall reliability and independence of the device is a critical item to consider during design.
- *Serviceability* – A modular design of this system provides adequate preventive and direct support maintenance. Common commercial components are used with the exception of the CPU.
- *Economical* – The overall design of this system focuses on maintaining a low-cost solution in order to increase the range of potential users.
- *Adaptable and Robust* - The system is able to adapt to different plant and pot sizes. It is also be able to adjust for and withstand various conditions for outdoor or indoor use. All components that are being used shall be made to withstand water, dirt, and any other elements that can arise from being in a plant environment.

2.3 Similar Devices

The PASS project is a portable built in system for personal use, wherever the customer might live. The pot contains most of the software and electronics necessary to provide an autonomous system for plant maintenance. The only thing the user needs is a smart phone or tablet, to be able to communicate with the PASS. Most of the similar projects are not portable systems; they are in ground systems for users that have gardens. However, the point of the PASS project is to allow usage by the individual who does not have the luxury of having a functional garden area. For instance the PASS project can be used on the porch or patio of an apartment or condo, or in a garden area with ground soil not suitable for growing edible plants. The projects summarized in the sections below do not have that luxury.

2.3.1 Automated Plant Growth System

This project was from the spring and summer of the 2009 University of Central Florida Senior design class. It "originated from the concern of food consumption for future generations," (Initial project description). It was a semi-portable hydroponics based system that regulates the pH of the plants, by measuring the pH and having a fertilization system that maintains the correct pH for the particular plants. The PASS does not have this function currently, though it could be a future improvement. However, watering is the main feature. The APGS mimics the light of day with artificial lights, which is an option for the PASS project, but it can use real sunlight as well as normal lights. APGS also measures the carbon dioxide, humidity and temperature, while the PASS measures temperature, as well as water moisture levels. The system interface is web based; therefore the system uses internet-based wireless, unlike the PASS, which uses Bluetooth. This is a project with different objectives and thus overall different design approaches to the PASS.

2.3.2 Growerbot

Growerbot is a box that is adaptable to the user's garden type; it is also an open source system that uses an Arduino network so it is easy to update and change to the user's specifications. It is a separate box that contains moisture, light, and temperature sensors, as well as a wireless connection. You place the probes where you want them, and connect it to your own water pump and light. It is not a fully inclusive system, since the user has to buy other things and have more open space to be able to contain the kit. The wireless functionality is used to connect to a social media site to update the user's online companions about how their garden is doing. The build-it-yourself kit is $95 without the wireless capabilities.

2.3.3 Growmanager

Growmanager is a greenhouse management system; it can be used with most growing environments; including hydroponic and soil. It controls all of the different systems within a greenhouse, including temperature, humidity, and carbon dioxide. Growmanager is just the software aspect of the system; all of the hardware is sold separately. But it can interface with multiple sensors with a data logger, as well as water pumps. The PASS project includes the software, as well as the hardware inside the system to provide full support and care of the user's plant.

2.4 Imposed Constraints and Requirements

The requirements of the PASS device follow closely with the objectives and goals of the project. In Table 2.4-1, each requirement is provided with a number, description, comments, and a priority. The last column of each table element contains one of the terms, essential, desirable, or optional meaning the component is either required, wanted, or nice-to-have, respectively. These

priorities helps distinguish the importance and helps make decisions on the implementation order of certain design components. This list of requirements is not limited and it shall be updated during the design and prototyping stages of this project.

Table 2.4-1			
Requirements			
Req.#	Description	Comments	Priority
001	Enclosure dimensions: 2.0'W x 1.0'D x 3.0'H	Enclosure dimensions: Width x Depth x Height	Essential
002	The enclosure assy. weight shall be less than 12 lbs.	Flexible instead of rigid exterior used for weight reduction.	Essential
003	There shall be min. Qty of 1 Lith.-Iron 12V battery for the system. 4.45"L x 2.28"W x 3.5"H Weight 3.5 lbs.	Optional B/U battery designed in system. Length x Width x Height	Essential
004	The system contains a component to provide solar power for recharging the battery.	4 Solar Panels, 7A Charger Ctlr, PVC Stand.	Essential
005	The sensors of the system shall be within 10% accuracy for their respective measurement types.	Overall sensor and data accuracy is important to ensure proper plant care.	Essential
007	The water pump shall have max. flow rate of 100 GPH.	A minimal pump rate thru 1/8" tubing shall support delicate plant care. (GPH=gallons per hour)	Desirable
008	The water tank volume shall be less than 2 gallons.	A small reservoir w/ external tank optional.	Desirable
009	Power cables 12 AWG oil resistant and rated for outdoor use.	10 AWG cable might be needed for extended length	Essential
010	The system's operating conditions are configured for outside and inside use.	This allows flexibility for the user and the plant may be kept in a natural environment.	Essential
011	The system provides a method for the user to control the PASS.	This allows for a user to interact with the hidden electronics.	Essential

3 Research

Each group member selected specific systems that comprise the device and accumulated data for each component within that system. Several different components were considered and compared based on attributes germane to the parameters of the project. Selection criteria of each component relied on several factors, which typically involved desirable component specifications that would

facilitate the operation of the device. Among the general specifications that drew the greatest scrutiny were usually size, operating temperature, power expenditure, and of course, price. In addition to component research, different methods of implementing sub systems within the project were also considered. This was necessitated by the dependence of differing system integration modalities based on the components that comprise the particular system i.e. the method influences component selection. Typically, before visiting vendor's websites, the group has read the theory behind the function of the component. Because our device entails some knowledge in materials, chemistry and fluid dynamics, most content we researched was beyond the scope of our classes. Regardless, such an understanding allowed us to make informed decisions regarding selection. Unfortunately, some vendors only listed a limited number of specifications on their websites. However, most vendors were more than willing to answer questions. Among the resources we utilized during our research were websites, textbooks, and journals. Also, the online textbooks and journals offered to UCF students from the UCF library were indispensable. A list of sources is provided at the end of this document in the Appendix.

3.1 Component Operating Conditions

The operating conditions are important to consider because the prototype could be based outside, so the outside climate determined the approaches to testing and design. A majority of the testing has taken place outside in the middle to late spring in Central Florida. While the design depends on the environment of Central Florida all year round, this is because even if the product is outside of Central Florida, it should be brought inside due to the colder weather to protect the plants. Therefore this section contains the Central Florida weather, as well as the considerations the project needs to take for the electrical components of the PASS.

3.1.1 Central Florida Operating Conditions

The PASS project has been tested outside, between the months of February and April, in Central Florida. The plant choice depends on the weather during the testing phase. So during this period the average temperature in the United States is between 5^oF as the low in February, and 83^oF as the high in April. The average rainfall in this period is between 2 and 4 inches, and the average relative humidity is equal to around 70% between February and April.

On the other hand, the design of the system needs to depend on the Central Florida weather for the entire year. The temperature is usually between 37^oF to 94^oF, with the humidity range as 41% to 96%, and the dew point average between 42^oF to 76^oF. This data tells us what the electrical components, as well as the enclosure material, whichs need to withstand on a daily basis.

3.1.2 Component Considerations

An issue for the PASS project is the electrical components within the project. Due to the weather and irrigation systems, the electrical components are in a

completely sealed environment or coated to prevent damage from low dew points and high humidity. The components themselves also need to be able to tolerate the different temperatures provided by the Central Florida weather, as well as the heating effects inherent to a sealed environment. Overall, the parts chosen for the design of the PASS must be studied for durability to the predicted environment parameters of Central Florida.

3.2 Plant Considerations

Every plant has different growing requirements; this includes diverse day length, light, temperature, water, and pH specifications. The testing environment has been in the middle to late spring climate of Central Florida, and the maximum length of the test was a few weeks. Therefore, for testing, the chosen plant needs to be a pre-seeded, small, short-term herb. The plant needs to be bought from a local area as a young plant, but not a seed, to minimize the testing time necessary. The plant type chosen needs to be able to thrive in a full sun environment; which means it requires more than 6 hours of direct sunlight a day, with regular watering to be able to stand up to the heat and sun of the middle to late spring Central Florida climate. The chosen plant needs to grow well in loamy soil; which is an equal mix of sand, silt and clay, because this is a popular type of planting soil. Statistically, the test plants need to be obtained from a variety of sources (such as Home Depot, Lowes, Wal-Mart, etc) to account for different source conditions.

3.2.1 Plant options

Dill: One of the options is dill, which is an annual herb that grows well with full sun exposure, in dry loamy soil. It does not require frequent fertilization to grow. It can grow to 1-3 feet tall and the plant can be up to 2 feet wide. Since Dill does not transplant well, it should be grown in its lifetime container from seed. This would be a poor option because of the testing time needed to be able to grow dill from a seed is very long.

Basil: Another option is basil, which is another annual herb that needs partial to full sun exposure in well drained, average to rich soil for optimal growth. The plant needs to be watered regularly, but not over watered. Basil is very sensitive to colder weather, and should not be in an area that is less than 50^oF. It is very tolerant of higher temperatures, which means it is a good plant for Florida weather. It is also acceptable to grow basil indoors under fluorescent and high-intensity discharge (HID) lights. It is a sturdy plant, with the ability to be transplanted, as well as a wide pH range, between 5.1 and 8.5. In optimal conditions, it can grow to 3 feet tall and 3 feet wide. Basil is good for growing in containers, which means it would work for the project's needs for testing time as well as be able to grow in the Central Florida weather.

Oregano: Oregano is a perennial herb that grows well in containers with full sun exposure in rich fertile soil. It can be started as a seed, or as a plant bought from a nursery. Oregano does not need as much water as some herbs, just when the

soil feels dry to the touch. When watering, water thoroughly and less often. In optimal conditions the plant may grow to 2 feet tall. Greek oregano is the best for cooking. This is a candidate for the project due to its flexibility.

3.3 Watering System

The watering system in the PASS project is important because most, if not all, plants need water to be able to thrive. Different plants require different watering techniques, and when the ambient temperature is warmer the plant needs more water to be able to survive intense heat. Therefore this system is connected closely to the soil moisture sensor, temperature sensor, and the micro controller. The watering system contains a pump, water level sensor, water tank, and irrigation system.

3.3.1 Ideal watering methods

An ideal watering time for most areas is to water the plants in the morning, since this prevents the sun from evaporating most of the water before it becomes useful to the plant, and also aids in prevention of mold growth because the sun evaporates the excess water. If the user happens to water the plants in the afternoon, mold and fungus growth could be an issue, because the sun does not have enough time to evaporate extra water from the plant, and the warm, wet, dark climate is optimal for unwanted growth.

Another type of watering is called deep watering; in this technique, the plant is watered slowly for a longer period of time, to get water down about 6 inches. This is so the deep roots get watered, not just the top of the plant and the top of the roots. This is good for plants that have already grown some, and their roots are deeper in the soil. This is also for plants that need the soil to be damp, not waterlogged; the plant may die if overwatered. This can be done with soaker hoses, or a drip system. This also promotes healthier root systems.

3.3.2 Pump Station

The basic pump element has two components: these are the direct current (DC) brush motor and gear assembly / impeller. When rotation of the assembly starts, a surge current of approximately 3 times the steady-state condition is generated.

For factory testing, distilled water was used to determine flow rate with a flow meter. The specifications listed are for "short-term operation" and the vendor does not guarantee the BA type or CA type for long-term operation. Our Green House application usage of the pump assembly has a small duty-cycle of 15% (approximate spec). The proposed pump's specified duty-cycle is 50%. The "Geared motor" endurance is greater than 1500 hours for the BA type and greater than 1000 hours for the CA type pump. A secondary pump assembly is optional to provide redundancy of the pump station. A power flow for the DC motor is illustrated in Figure 3.3.2-1.

Power Specifications:

BA Type: Power In = 12vdc x 0.4Amps _{max} -> 4.8 watts   (theoretical calculation)

CA Type: Power In = 12vdc x 0.25Amps _{max} -> 3.0 watts   (theoretical calculation)
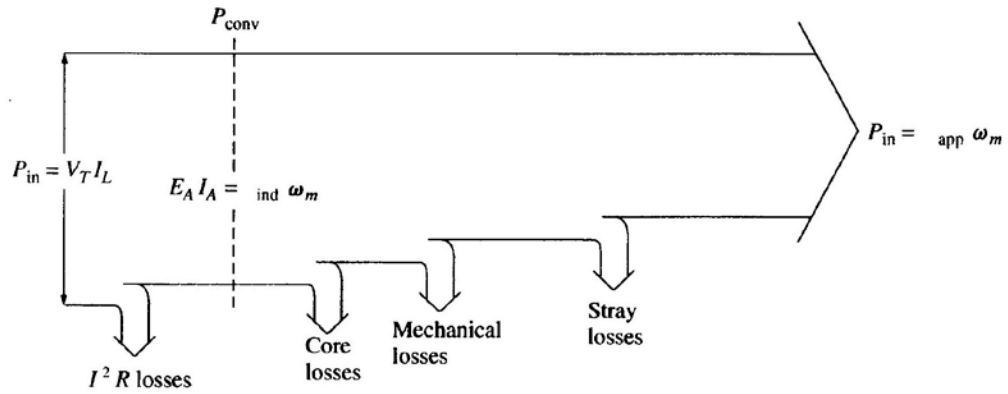
Figure 3.3.2-1; This is reproduced with the permission of the McGraw-Hill Companies; ELECTRIC MACHINERY FUNDAMENTALS (Chapman, 2005)

The mechanical power that is converted from electrical power, depicted by P_{in}, is given by the equation below:

$$P_{in} \ = \ _{app} \ \omega_m$$

The efficiency of a typical DC motor is rated up to 84.2% accounting for all the losses noted in the DC machine power flow diagram.

The illustration below in Figure 3.3.2.1 is a power flow diagram of an alternating current (AC) induction motor. This type of pump was considered early in the design process but was replaced with the DC pump. The illustration provides insight on the losses incurred with the motor alone. The efficiency would be degraded further with applied power coming from the inverter.
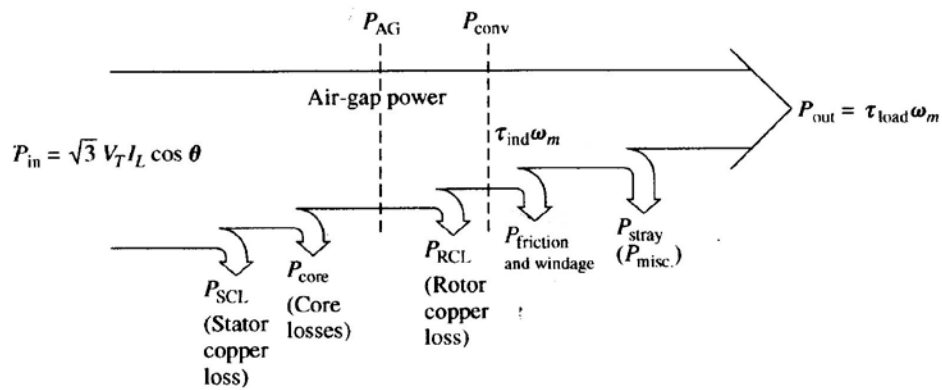
The power-flow diagram of an induction motor.

Figure 3.3.2-2; This is reproduced with the permission of the McGraw-Hill Companies;
ELECTRIC MACHINERY FUNDAMENTALS
(Chapman, 2005)

The mechanical power that is converted from electrical power is given by the equation below:

$$P_{conv} = \tau_{ind}\, \omega_m$$

The efficiency of a typical A.C. induction motor is rated up to 83.7% accounting for all the losses noted in the induction motor power flow diagram. The options for water pumps are summarized in the subsections below:

66GPH: The 66 gallons per hour (GPH) pump is submersible, with a max lift of 2 feet 4 inches. The dimensions are 1.97 inches in length by 1.73 inches in width by 1.26 inches in height. The pump requires 120V AC at 60Hz, with 3 watts of power usage.   This pump can be used with 5/16 inch and 1/2-inch tubing. This pump is priced at $11.99.

60GPH: The Beckett 7206410 60 GPH fountain pump, pumps water at a height at 1 foot it pumps 60 gallons per minute with a maximum height of 30 inches. It connects only to 1/2 inch tubing. The price of this pump is roughly $18.98.

70GPH: The 70 GPH statuary pump has a maximum height of 2 feet, uses 3.6 watts, with 120VAC and 0.03 amps. Using 1/4 or 1/2-inch adaptors for water flow. It is submersible, and can be used for fresh water or salt water. The cost of the pump is $13.60.

12VDC: The 3.8L 12V Mini DC submersible Water Oil Pump has an input from 9V-12V, with the maximum height equal to 8 feet at the 12VDC. At 12V the pump

requires 500mAmps. The water input valve is 13.8 or 9 millimeters in diameter, or around 1/2 or 1/3 inch. The output can either be at a 7.2 or 5mm diameter. When it is never run dry the pump has a lifespan of 20,000 hours. The cost of this system is $14.50.

3.3.3 Irrigation systems

An irrigation system is necessary, because there needs to be a way to get the water from the reservoir to the soil in an efficient way. The PASS project needs the best irrigation system for smaller pots that may or may not be located indoors.   Therefore one of the requirements for the irrigation system is that it needs to water plants with a low flow system that only waters the plant, and minimizing the escape of water from the system. This requirement also works with the efficiency needed for the water tank. The water reservoir needs to be as small as possible, to let the weight and size of the total system be as small as possible.   There are several different types of irrigation systems that can achieve this requirement. Those systems include; drip irrigation, soaker hoses, and misting systems and each one is described in the following sections.

3.3.3.1 Drip irrigation system

Drip irrigation systems are a slow way to water plants, with 90% efficiency as opposed to a good sprinkler system, which has 70% efficiency. It is a low water pressure system, through plastic pipes to get the water to where it is needed. Water is frequently applied at a low pressure, with a goal of only applying the water when the plants need it and maintaining an optimal balance of air and water to distribute into the soil.

The drip system can be installed directly above or below the soil. This minimizes water waste due to evaporation, run off, and wind.   This means it is very good for home gardens in drought areas as well as areas where it is difficult to have home gardens due to difficulty in watering. Most drip systems work well with an automated watering system for people with busy lifestyles.   They are very adaptable to the type and size of the garden, as well as being flexible to change of location of the plant.

Water loss can occur if the system was not installed correctly, or adapted to a new garden arrangement. This could also cause restricted plant growth, because of where the water is located. The systems also need regular maintenance, because they may become clogged due to unfiltered water or inappropriate water pressure. If improperly installed it may also be a trip hazard.

The drip system must be designed to the plant needs; the emitters (or where the water comes out) are required to be placed where the water can reach the plant's roots. As the plant grows the emitter placement must change as well. The PASS system needs one to two 0.5 GPH emitters per plant. Larger plants require more emitters at higher Gallons per hour rates. This can lead to a more expensive system compared to using other options.

3.3.3.2 Soaker Hose System
A soaker hose system contains a hose that is made of a thick polyethylene, with tiny holes for the water coming out. This hose is attached to either a pump or a water facet. The hoses are usually placed on the ground, underneath a layer of mulch, but they can also be placed below ground. They can be a small system, or cover a very large area with mixture of soaker hoses and solid hoses attached to each other. This is done with a good initial flow at the water input of the system. The systems need to be installed a few inches from hard surfaces that absorb heat, to reduce absorption from those surfaces.

Soaker systems supply water at a slow steady rate on the root area of the plant. This lets the plant's roots stay moist, and prevents water evaporation, run off, and fungi growing on the plant leaves and stems. The above ground system is easier to install than the underground, and it can also be moved around very easily when the garden arrangement changes. The underground system is more difficult to install, but has more watering benefits, has less evaporation than the above ground systems, and is less of a tripping hazard. For the PASS project, the need is for a very small system. The system can be built out of different materials to be small enough. It must also be able to interface with the chosen water pump.

3.3.3.3 Mist System
This is essential for greenhouse enclosures; it provides consistent conditions all year long. So it provides humidity and cooling for plants in low humidity and high temperatures. Misting systems provide moisture to the plants, and cooling when they are too hot to germinate. This type of system can also lower energy costs in terms of using moisture as cooling instead of air conditioning units or fans. Using this as a cooling device provides more consistency than fans as well.

3.3.3.4 Water Tank
The PASS project requires an integrated water tank for the irrigation system. It also needs to be portable, thus the water tank needs to be as small as possible. It also needs to act similar to a rain barrel, refilling itself from rain, or being refilled by the user. The tank also requires something that directs the water away from the plant and electronics if the tank is overfilled. It is essential that the tank is small enough to transport with the rest of the PASS project, but it also needs to be big enough to hold the chosen pump, water level sensor, and tubes crucial to the irrigation system. It also needs an opening large enough to be able to take out the pump for maintenance as necessary. If it is being refilled from natural sources such as rain, an overflow control is needed.

The material the water tank is created from is a type of durable waterproof material. Holes from irrigation tubes and electronic components, as well as the openings in the top of the tank cannot make the tank collapse. It also needs to be rigid enough to be able to separate the electronics and the water without

changing shape whether the tank is full or empty. Another requirement is environment durability, because if the PASS is outside most of the year it needs to last through many different types of conditions, including resisting most sun damage that often causes some plastics to quickly disintegrate. These requirements can be met in several different ways; one example would be hand building the tank roughly using Plexiglas and caulk. The device can also be injection molded with strong, durable, polyurethane materials designed to withstand varying environmental conditions.

3.3.4 Water level Sensor
Since the tank may not always have water, the system needs a sensor to be able to tell when not to turn on the pump. When the water sensor reads the tank as empty it sends a notification to the user via the interface provided with the PASS. Thresholds can be set in order to indicate that the tank has a certain amount of time left until empty due to normal usage. Green house temperature affects the status of water in reserve.

3.4 Distributed Sensor Network
The feedback network consists of the distribution of sensors that allow the conditions of the plants environment to be detected. The state of certain conditions of the plants environment determines its viability and the accurate detection of these factors is contingent on the sensors; therefore they are pivotal in the operation of the prototype. Factors such as the pH of the soil, moisture of the soil, light exposure, temperature, and air quality are captured with detectors. The value of the voltage generated by these sensors is sent through a signal path; an amplifier, biasing circuitry and an analog to digital converter before being sent to the microcontroller, usually conditions the signal. Interfacing the sensors to the microcontroller represents one of the biggest challenges related to this project but they also serve as the primary drivers that allow us to determine the design and features of our project.

Some of the sensors in use are not interfaced directly with the microcontroller, so dismantling the sensor housing and identifying the signal path in the sensor and connecting it to the microcontroller was an anticipated issue. Some aspects that contributed to the selection of a sensor are unique to that particular application but generally depend on price, usability, product lifetime, brand reputation, durability, sensitivity (range of measurement), meter size, sensor calibration, operating voltage and operating temperature. The microcontroller must have the appropriate number of I/O ports and since most of the signals generated from the probes are analog, the ports must have analog to digital converters. The controller must tolerate the operating voltages of some of the sensors.

When the values generated from some of the sensors are processed by the microcontroller, they can activate a certain response. Our project requires programming the controller to continually detect sensor values and activate a response if the controller, based on how it's programmed, interprets a signal generated from a sensor that is hazardous to the plants environment. For

instance, if the moisture sensor sends a signal to the controller and the controller determines that the soil is too dry, the controller activates the water irrigation system. In this way, the operation of the water irrigation system is dependent on the value generated from the soil moisture sensor and the program written in the microcontroller is created accordingly. Likewise, a hazardous value from the pH sensor will alert the user to adjust the pH. However, the operation of the pH value is coupled to the value measured from the moisture sensor because the soil pH sensor is only operable in moist soil. Using a tablet on a wireless network, a user may manually override the activation of certain components, whose operation would be normally contingent on the value of a sensor. The following sensors and the resulting action they elicit when a hazardous value is detected are displayed below:

Soil moisture Sensor: The purpose of this sensor is to monitor adequate moisture levels in the plant soil. When a voltage value that corresponds to an unacceptable amount of moisture is obtained, the controller activates the irrigation system promptly. A condition must be programmed into the controller to differentiate controller response based on input voltages from the sensor into the controller. This sensor governs the activation of the irrigation system, although the user may also activate the irrigation system manually.

Soil pH Sensor: The soil pH meter detects the pH (amount of dissociated [H^+] in a solution) of the soil. Because pH readings are only accurate in moist soil, the soil moisture sensor is also coupled to the pH sensor; if the soil moisture sensor detects the dryness within a certain margin, the reading from the pH sensor is ignored by the microcontroller. Unlike the soil moisture sensor, a reading that would correspond to a pH hazard, does not elicit any response within the system but it does cause the controller to send a message wirelessly to alert the user of the pH value.

Photo-Detector: Light is obviously vital to the growth of plants. The purpose of the photo-detector is to measure the output of natural and artificial light and then send the acquired data to the controller, which, based on certain conditions, would potentially activate the lighting assembly. The photo-detector is to be connected to the microcontroller and coupled with the controller's timer. Regarding the photoperiodic nature of plants, timing issues associated with this sensor-controller interface are especially important. For example, the controller must ignore sensor readings at night that would otherwise activate the lighting apparatus. Instead of using this sensor, we are considering activating the lighting assembly only when the solar cells in the power assembly are deactivated. This requires considering the sensitivity of the solar cells. Further elaboration regarding this option will be provided in the research and design sections.

Thermometer: Like the pH meter, the thermometer does not activate any device within the assembly but the signal it generates is sent to the microcontroller. If the temperature occupies an undesired margin, the user receives an alert from

the controller via the wireless module. We are considering placing a ventilation fan in the assembly, which activates from the controller based on a reading from the temperature sensor.

Water Level Sensor: Attempting to pump water from an empty container is not only a silly waste of power. It is dangerous! Sensing the water level in the reservoir and deactivating the pump when the water no longer adequately submerges the pump is the purpose of this sensor. Connected to the microcontroller, a signal indicating a low water level causes the controller to send a reservoir refill alert to the user wirelessly, via the wireless module. Also, when this sensor detects a certain lack of water in the reservoir the irrigation system is never be activated even if the soil moisture sensor detects dry conditions.

3.4.1 pH Sensor

The pH scale, p meaning "potential" and "H" meaning "hydrogen", is a unit less measure of the basicity and acidity of a solution. The pH value of the soil is important to plant growth, governing nutrient uptake and pathogen regulation. This device incorporates a pH sensor to monitor pH value. Before we proceed to sensor criteria and selection, a brief description of pH is provided. A hydronium anion H_3O^+, abbreviated equivalently as H^+, is considered acidic and a hydroxide anion (OH-) is basic (alkaline); these ions appear as pairs in a solution, one is the conjugate of the other. pH is dependent on temperature, the pH values that appear in most common mass published tables are based on 25^oC, approximately room temperature. A greater temperature facilitates the release of the H^+ ion, lowering the pH value, creating a more "acidic solution". This proportionality can be observed by inserting the value of the molar concentration (expressed in brackets as $[H^+]$) of the hydronium ion into a negative logarithmic equation:

$$pH = -log[H+]$$

Since the pH value of the acidic hydronium ion is the negative logarithm, a smaller pH value corresponds to an acidic solution that has a very low pH. This logarithmic relationship means each successive value has a pH ten times the previous value. Since the pH scale is from zero to fourteen, a pH of seven is considered neutral; a value above seven is basic and below seven is acidic. The molar concentration (moles/liters of solution) of hydronium ion $[OH^-]$ in the solution may be determined by simply subtracting the pH value from 14.

$$pOH = 14 - pH$$

The pH of the soil determines the solubility of certain substances in the fertilizer and therefor the bioavailability of nutrient uptake in the roots of the plant. A pH range not only determines which substances the plant absorbs; it also determines with equal importance regarding toxic substances, which substances are not. It is apparent from the diverse growing conditions and environments of many plants that optimal pH range varies with respect to differing plant types.

Certain microbes are inimical to the growth of the plant, while others nurture it. The viability of either type of microbe is determined by the value of the soil pH. However, according to Buchanan et al, a pH of 5.5 to 6.5 is ideal for many plants and most vital substances are not dissolved in a pH greater than seven.

The pH meter is typically composed of two semi-permeable, high impedance glass electrodes (although other materials are possible). Semi-permeable in that the H^+ ion may diffuse across pores in the glass to a silver wire coated with silver chloride. One electrode serves as the reference electrode, held at a constant voltage potential and pH usually of 7, while the other serves as the electrode that actually measures the substances pH. The H^+ ions create a potential difference across the glass electrodes that are proportional to the ionic concentration i.e. the pH. The size of the potential difference depends on the difference in concentration of aqueous hydrogen ions on the inside and outside of the membrane. Since the pH of the reference electrode is fixed, the potential difference depends on the pH of the outside solution. As an aside, many problems with pH meters may be traced to a leaking reference electrode, regardless of the price of the device.

Since many substances are soluble only at a narrow pH range, the sensitivity and accuracy of the pH sensor are of upmost importance. There are several different types of pH sensors available; the operation, cost, sensitivity and structure of the device serves as the criteria in selecting the most optimal sensor for this project. Ideally, the pH sensor is to be interfaced with the microcontroller. If the actual pH value deviates from a predetermined range programed into the microcontroller, an alert is wirelessly sent to the user and they may adjust the pH accordingly.

A particular problem that the group encountered was most sensors were not designed to interface with the microcontroller; the value measured from the pH sensor was displayed on a built-in LCD on the pH sensor assembly. This presented a problem because the voltage / signal from the probe that represents the pH was sent to the built-in LCD instead of its desired destination of the controller. An ideal pH meter configuration would have wires that carried the signal from the sensor exposed, so these could simply be connected to the bias circuitry path to the controller. To a certain extent, this configuration limited our options. However, it would be feasible to obtain such a pH meter, dismantle the device and identify the wire that carries the voltage signal from the probe and create a new signal path to the controller. This wire may be connected to an amplifier, to expand the signal. After that, the analog signal may be sent to the analog to digital converter before reaching the controller. Likewise some meters need power to operate, so it would also be important to identify its power source and connect it to the systems primary power source. For our purposes power is only needed for the LCD and not the actual sensor, so this is not an issue for this project. The ions from the soil actually generate the signal, so the pH meter is a

passive device. The complications that arise from dismantling the probe will be elaborated on in the design and prototype sections of this report.

The price range for a pH sensor varied greatly and the required specifications and characteristics of the sensor must meet the needs of our project. The price disparity of the meters may be attributed to the types of features they offer, this being especially true regarding the graphical display on the LCD screen. Since we do not intend to use the built in LCD, such features are extraneous to this project and therefore our pricing options are expanded to include less expensive alternatives. Also, the measurable pH range of the meter contributes to the price of the sensor. Most of the higher end, expensive meters have a measured pH range from 0-14 however, for our purposes a limited measured pH range would suffice, further alleviating our expenses. The specifications of the pH meters that drew the most scrutiny for our project follow:

The needed measurable pH range of our sensor is quite narrow because the plants pH requirement is narrow. This actually works to our benefit because limited range pH sensors are less expensive than full range pH meters. However, some higher end meters feature greater sensitivity within a narrow range.

Another caveat that was encountered regarding the selection of the pH meter was that of pH variance with respect to temperature. As the temperature changes the corresponding pH does so as well, since the equilibrium of most reactions, specifically in this case. The quantity of $[H^+]$ ions is dependent on temperature. Some pH sensors provide a feature called "temperature compensation" in which the variance of pH with respect to temperature is accounted for by a temperature sensor within the device. The temperature variance is "compensated" for and the resulting pH is processed scaled to $25^{o}C$. Since our project required autonomous operation, our device requires a pH meter with this capability. Because of the temperature sensor, these sensors are a bit more expensive, so careful investigation and possible design compromises must be made with respect to this sensor.

The size of the glass correlates to response time, a thicker glass has a slower response time but it possess much more durability than a thin glass membrane. Likewise, a thin glass probe boasts a faster response time but is less durable. For the needs of this project, a slower response time and consequently, a thicker glass are acceptable.

There are many challenges associated with the pH meter other than interfacing the meter to the controller as previously mentioned. Calibrating, cleaning and storing the meter represent imposing challenges insofar as they require human intervention. A pH sensor must be recalibrated after a certain number of uses. Recalibrating the sensor entails soaking the probe in a solution with a known pH value and then manually adjusting the pH value on the meter. Because such recalibration requires removing the sensor from the environment entailing human

intervention, it reduces the autonomous feature of our project. Although, so called automatic calibrated pH sensors exist, the calibration is not truly automatic; the steps for calibration are simply reduced and human intervention is still required. Likewise, cleaning the sensor is important because the analyte adheres to the probe during each measurement. Without cleaning the probe, each successive measurement is less accurate because the probe is contaminated. Cleaning the probe cannot be completed automatically, so this too interferes with our objective of total autonomy. However, the probe would only need to be cleaned about once a month, preferably by simply rinsing (not scrubbing) in a cleaning solution or even water. The storage of the pH sensor entails soaking it in water, if the glass electrode is dry for too long, the sensor ceases to function properly and its lifetime diminishes greatly. Again, this cannot be completed automatically and requires the pH meters removal from the soil when the soil becomes dry.

There were many pH sensor options from which to choose; however, many models share similar features and prices. The following synopsis serves as a description of the devices we found particularly amenable to this project. Elaboration of their advantages and weaknesses are provided below:

Hanna Instruments Checker pH tester HI98103-716435: This $36 sensor boasts a reading with an accuracy of 0.01pH. The electrode on the device is easily replaceable, requiring a screwdriver to replace the electrode. A battery life of 3000 hours is impressive but that is primarily for the onboard LCD, which we are not be using for this project, so this feature would not serve our purposes. Also, the range of the pH sensor is from 0 to 14; however, our plant requires a pH in a range from 5 to 8, limited by the measured values for soil.

Rapitest Soil Mini pH Meter 716753: Unlike the other digital sensors, this meter lacks an LCD so at $10 it is much less expensive. This model stood out because it was the only pH meter identified that was purely analog; it utilizes a needle to display the pH. Because of its very low price, the pH meter most likely is not capable of temperature compensation. The vendor must be contacted to verify this. We may not select this model to be implemented in our final device but it would be a low cost option for prototyping.

HM Digital pH meter716155: The feature that distinguishes this pH meter from other options is that it is capable of automatic calibration. However, as previously mentioned automatic calibration still requires human intervention; the process may be completed on the interface of the device by pressing a few buttons. Most pH sensors capable of auto calibration have a pH range reading of 0 to 14, and again, for our purposes, a narrower pH range is preferable to reduce costs. The resolution is 0.1 pH and the glass encased reference electrode helps retain moisture.

BlueLab Soil pH Meter: This meter seems promising because unlike the others, it has a BNC connection. This is a very desirable feature for our project design because we could avoid dismantling the meter, slicing the wire and connecting the wire to the controller. With the BNC connecter however, we may connect the BNC on the pH meter to an intermediate board and make a connection from the box to the microcontroller. These features come with a price; the BlueLab meter is $83, which may be too expensive for our budget. We needed to consider overall integration time and costs.

3.4.2 Moisture Sensor

A moisture sensor is used in the PASS project to check the moisture content of the soil. This is necessary because plants require a certain amount of moisture. Then different plants thrive on different levels of moisture. Some want the soil moist all the time; while others can handle dryer soil. However, the plants that want moist soil still die if the soil is too wet. This is why the moisture sensor must be able to identify the different levels of moisture in the soil. The placement of the sensor is underground, and has power to it only when the user and plant require it. There are a couple different ways to measure the moisture levels. One example is measuring the conductivity, for instance; this is because water changes the conductivity in the soil. Another way is to measure the dielectric constant, which is similar, but has less calibration issues. The different options are as follows.

VH400: Vegetronix produces a Moisture Sensor Probe that is a high frequency source to provide precise low cost moisture monitoring. It measures the dielectric constant of the soil between transmission lines; this is so it does not corrode over time. As well as not being sensitive to the salt levels in the water, corrosion can cause errors in conductivity measurements. The output voltage changes with the different moisture levels.

The sensor requires a current is less than 7 mAmps, with an output impedance of 100k ohms, and the supply voltage between 3.3V to 20 VDC. The output has 2% accuracy, with an output range of 0-3VDC depending on the soil's moisture content. The operational temperature is between -40 to 85°C and -40 to 185°F. The sensor functions well in pots, as well as larger areas. It has a design aimed at long-term use underground as well as on top of the ground. $36.95 is the price of the sensor.

Grove: The Grove moisture sensor is conductivity based. It is design by Seeed Studio, and only works with their systems; this is an Arduino development kit (the kits are sold separately). They are not built for constant use, because the sensor oxidizes very quickly. It is also built to measure the water content of the topsoil, not the deep soil. The individual sensor's price is costs $4.90.

EC-5: Decagon makes the EC-5, which is a moisture sensor that is not very sensitive to the salt concentration of the water. This is accomplished by

measuring the dielectric constant using frequency. Factory calibrations are included for a few different soil types. Being easy to install, and durable enough for the field and pots. The analog signal also means easy integration with other systems. This sensor is for small volume projects with a tight budget.

Accuracy depends on the type of soil but ranges from 1-3%. The required input voltage ranges from 2.5-3.6 VDC with a 10mA current. The output is a voltage that changes with the moisture concentration. The operating temperature ranges from -40^oC to 5^oC, or -4^oF to 122^oF. The system required needs to be capable of switching from 2.5 to 3.6V and have an end voltage measurement at 12-bit resolution or better. The price of this sensor is $110.

GardenBot: The GardenBot soil moisture sensor is a sensor you build yourself that measures the different resistivity in the soil. It requires 12 gauge galvanized steel wire, packing foam block, soldering iron, solder, and lead wires. Different temperatures affect the resistivity of the soil; therefore there can be false readings because the soil temperature is too high. Also because of using direct current there is electrolysis; only turning on the sensor solves this when you want results, instead of reading it all the time. This sensor requires more separate testing because the group will be doing the calibrations.

3.4.3 Grow Light Assembly
LED operation of the light-emitting section of a typical LED is composed of n-type and p-type semiconductors joined together. When this junction is forward biased, electrons combine with holes and thus photons are discharged. The wavelength of these photons is critical to plant growth. Natural sunlight emits the full spectrum of all colors of light. A table is listed below for various color wavelengths.

Some plants grow well using blue light while others grow better using red light.
In order to "light up" an LED, the applied voltage must be greater than the LEDs bias voltage V_{LED}, and limit the current flow with a series resister to a particular level below the LED's maximum rating, I_{LED}. The equation listed below is used to set the series resister value:

$$Rs \ = \ (Vin - VLED) \ / \ ILED$$

In order to adjust the brightness of the LED, the PASS incorporates a 1k potentiometer into the design. This extra component is in series with the rest of the circuit shown in Figure 3.4.3-1.
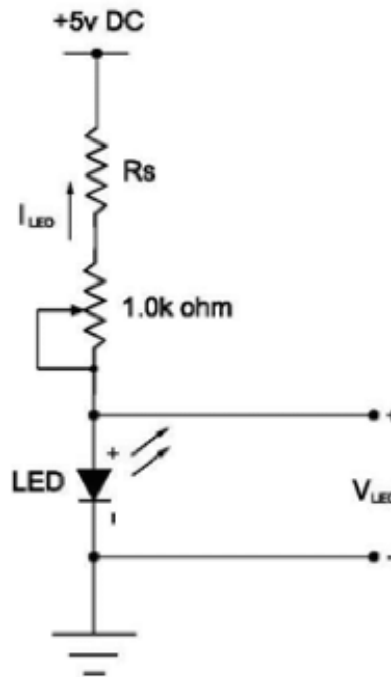
Figure 3.4.3-1: Grow Light Assembly
Important: V_{in} > V_{LED} or the LED will not illuminate!!

For this project, we have one light for one plant. The light bulb is be activated from the microcontroller when the sensor detects darkness for an extended period of time based on the length of the light interval needed for the particular plant. The user may also wirelessly activate the lighting assembly from their tablet using a local area network. To some extent, the lighting assembly is dependent on the greenhouse enclosure of the prototype. Because, primarily based on price and size, we are limited in our choice of greenhouse enclosure that is prebuilt; we intend to build the lighting assembly to conform to the greenhouse form factor. The components of the assembly include fasteners, grommets, power inverter, and wires. Fabricating the assembly would require a great deal of acumen in carpentry and/or welding, skills most of us in the group lack. Instead of building and assembly we may opt to purchase an existing apparatus. The disadvantages to this method are cost and choice of form factor of the assembly, since we wouldn't have the freedom to design around the shape of the greenhouse and are thereby relegated to a predefined shape.

3.4.3.1 Grow Light
Selecting the appropriate grow light for this application was critical for obvious reasons. A plant obtains its energy from photosynthesis, by converting sunlight and carbon dioxide into sucrose and oxygen. This simple explanation of photosynthesis does not help us in the design of the lighting assembly and selection of the proper grow light we need, so a more thorough understanding of the process of photosynthesis was needed. Initially, we believed a superficial understanding of this process was sufficient in selecting an optimal grow light;

however, learning the nuance of the process revealed that there were unlikely pitfalls. For instance chlorophyll is a photoactive pigment that allows plants to absorb light of a specific wavelength. Knowledge of such issues allowed us to be cognizant of useful specifications regarding grow lights and the design of the lighting apparatus. We do not want to spend too much money on this part of the project but we realize the importance of this subsystem, so our due diligence regarding this acquisition was especially needed.

Considering the growth of our plant and the fact that the theoretical efficiency of photosynthesis is only 30% while the actual efficiency is 1% to 4%, informed selection of the grow light was needed for the viability of the plant. The reason why different plants absorb different parts of the spectrum is because each plant contains a variance of pigments; primarily chlorophyll A and chlorophyll B, in addition to this, secondary; "accessory pigments" are also present in varying amounts. Each pigment possesses a specific absorption spectrum and the contribution of each spectral component is contingent on the amount of pigment present in the plant cell. To achieve proper symmetrical growth, the plant needs different spectrum components during its specific growth stages. The wavelengths on the absorption spectrum correspond to different color temperatures in Kelvin that the light generates. The blue violet region of the spectrum causes the plant to widen while the red-orange region causes the plant to shoot vertically. The physiology of the plant is also contingent on receiving the needed spectral components. The upshot to this was to take into consideration during research, the spectrum of radiation our light would generate. With Cognizance of this information, it also became clear to us that awareness of the plants absorption spectra would dictate which light we select.

Each type of plant requires differing amounts of light for growth. Such disparity results from the plants phototropic nature; they require light in certain cycles (similar to The Circadian rhythm for humans). Constant light would be inimical to most plants survival, although some plants are able to withstand such conditions. Consequently, the length of each dark/light cycle is unique to the type of plant. In addition to this, the color temperature of the light is also an important factor that governs photosynthesis and like the aforementioned regarding light quantity, many different plant types require different color temperatures to thrive.

Designing the lighting apparatus is integral since its function determines the plants ability to harvest energy via photosynthesis. Light on/off cycling, amount and color temperature are important regarding the plant. Expenditure of heat from the bulb is a concern as well; we want to generate an adequate amount of light but also avoid creating excess heat that would harm the plant. These variables have certain units and each bulb type has a differing set of unit values and specifications. Each bulb possesses a certain color temperature, measured in Kelvin (K), a power rating (Watts), and unfamiliar to most, a light output value called the lumen. During research regarding the quantification and measurement of light, we were confronted with a bewildering amount of lighting units and it was

not always clear what they were based on. Indeed, photometry is a large subject within itself. Despite the vast amount of units used to measure light, most vendors provided only a Watt rating, which is actually just a measure of power. Other than the Watt, the unit we encountered most during research involving the selection of the grow light was the lumen. Contrary to what the average consumer is led to believe, power is not necessarily related to light output; a larger wattage does not always equate to greater light output. Other than the watt, the only unit most vendors included was the lumen, which is a measure of light output. This unit too, had certain limitations, as we later see. Different bulb types generate various lumen/watt ratios. Inefficient bulbs like the incandescent may expend a great deal of heat but generate very little light. To that end, a more expensive LED would be desirable over the cheaper incandescent bulb, and the product lifetime of the LED is also greater than an incandescent.

The definition of the lumen is based on human perception of color and light. The range of light the lumen governs does not apply the absorption spectrum of plants, and in fact part of the range of light the chlorophyll may absorb falls outside the range of human perception rendering the lumen irrelevant for this application. Moreover, humans perceive part of the spectrum that is almost useless to plants i.e. the color green. For this reason, leaves appear green because they reflect, rather than absorb radiation of that wavelength. The region of the spectrum that is useful to plants is the Photosynthetic Active Radiation (PAR); any reputable grow light specification list should mention this feature. To our surprise we found most vendors did not. The PAR is defined as energy per area and is applicable for wavelengths of 400-700nm. Lights that do not feature this spectrum generate light that is not conducive to the growth of the plant, thereby undermining the growth of the plant and wasting energy from the power source. Plants have evolved to respond to different colors of light at different stages of its growth (vegetative, fruiting, reproductive and flowering). If a plant is grown with only one color it may affect the growth of the plant (e.g. it may grow significantly more in the lateral direction or vertically).

Grow lights are available in many form factors and correspondingly, different types of bulbs feature different bases. Awareness of the base of the bulb is important because it determines which light assemblies to hold the bulb that we are limited to selecting. This is also associated with the power system and microcontroller arrangement, inasmuch as the lighting assembly is directly connected to these systems. Since we are primarily considering an LED for this device, the base standards associated with this bulb type that we should be cognizant of is the Edison Screw Mount (E) Standard or the bayonet mount, which is inserted into the mount by twisting the bulb in the socket and snapping it into the pins. Like the E26 standard for the screw mount bases, the G24 designates the bayonet mount. Both sockets are commonly used for household applications. Although, the bayonet mount is used predominantly for the halogen bulbs. However, the fixture must be capable of supplying direct current to the bulb and not alternating current, as our power system is designed for direct

current. If this is not possible we may have to use an expensive heavy inverter to convert DC to AC, and a correspondingly larger battery pack and charger. The socket fixture in which the base of the bulb is inserted may have two or three wire leads connected from its base. These wires correspond to the hot wire, which carries the current into the fixture, the neutral wire, which transfers the current out the fixture, and the ground wire. If a fixture has only two wires, one is the hot wire while the other is always neutral.

Most fixtures include a switch, which we do not need since the bulb is be directly connected and activated by the controller. A keyless socket does not include a switch on the fixture, instead it is activated from a wall switch, and they are primarily intended for domestic applications. If we must purchase a mount with a switch, then it is permanently switched on and it receives current from the controller when activated. Otherwise, we intend to purchase a keyless E26 weatherproof socket. Many vendors sell shields that surround the enclosure and prevent them from getting wet. This design complication has been addressed in the design section.

Each lighting modality, whether it is LED, CFL or Incandescent, offers certain merits as well as unique specifications. Employing the best choice is a function of our design and the needs of the most optimal outcome of our project. Factors that have been mentioned before include light output, heat generation, power expenditure, cost, size and usable spectrum for the plant. In addition to using lights for plant nutrition, some growers in cooler climates rely on their grow lights to produce heat, which when generated from all lights is infrared radiation. Plants utilize this heat for many functions including, respiration, photosynthesis and transpiration (water transfer). Since this project is developed in Florida, the heat needed for the plant is naturally provided by the climate. Consequently, it is important to realize the heat generated from a bulb is only an issue for this application and not the bulb in general, as some growers need the heat. However, with consideration to diverse growing conditions, we intend to choose a versatile fixture that can hold a high and low heat-generating bulb. We now consider the familiar types of lighting such as LED, compact fluorescent, halogen, incandescent, high intensity discharge and high-pressure sodium.

Compact Fluorescent: Compact Fluorescent lights have the same characteristics of the regular fluorescent type: however, they are much smaller and feature the familiar Edison Mount screw base. The distribution coverage of the light generated from the fixture is even and broad which contrasts with the narrow coverage of the LED. Although they do not produce as much light as halogens, they possess much greater efficiency and have much longer lifetime than halogen lamps but not LED's. While these lamps produce very little heat, they do contain sealed trace amounts of the element mercury, which is toxic. Ostensibly, this poses no significant danger, however, due to the rugged weather conditions the device may be exposed to, the enclosure may fall, cracking the

bulb and releasing some mercury. For our project, the mercury would likely be trapped in the container, and could be then properly disposed.

LED: The LED produces the same amount of light per watt as the ultra-efficient CFL but lasts tens of thousands of hours longer; consequently, the LED is a very attractive option. Heat output is held to a minimum and many growing applications utilize LEDs. Unfortunately, a major drawback is the narrow coverage it offers; the light is not uniformly distributed. However, a parabolic reflector may ameliorate directionality. Cost is also an issue as this option is the most expensive. Another limitation of the LED is that the spectral distribution of its light is not as varied as the High Pressure Sodium, CFL and High Intensity Discharge bulbs. Higher end LEDs are capable of generating multispectral light by modulating the spectral distribution of the light output, which is superior to the other lighting options; however, these LEDs are very expensive.

Halogen: Like the compact fluorescent lamp, the halogen boasts efficiency and while it generates more light than the CFL and is non-toxic, the heat output is, unfortunately, tremendous. Like the incandescent light that preceded it, the Halogen contains a filament in the bulb's vacuum interior. However, unlike the usual incandescent, the interior contains a halogen gas, which recycles the vaporized tungsten, returning it to the filament. The heat generated from these lamps and their lack of efficiency compared to other options does not bode well for its prospects regarding this project.

Incandescent: Cheap, inefficient and with a limited operating lifetime, the familiar incandescent bulb is compatible with the E26 base but the very low price is really its only desirable attribute. The ratio of light to heat generation is prohibitively low for our application. Despite possessing features that are so inhospitable to plants, there are incandescent bulbs specifically manufactured for growing plants. These bulbs even possess a tint coating that acts as a filter to pass the red/blue color needed for plants to thrive. However, as these bulbs only last for hundreds of hours, compared to CFL's and LED's which last over tens of thousands hours and generate so much heat, we are all in agreement to spend an extra $10-$30 for a more optimal selection.

High Intensity Discharge (Metal Halide): Of all the lighting options considered, the metal halide lamps produce the widest usable spectrum for plants, closest to matching sunlight. Although the output of this lamp is slightly weighted toward the blue-violet part of the spectrum, this does not pose a significant problem for growth. HID is slightly less efficient than high-pressure sodium and much less efficient than CFL or LEDs. Unfortunately for this project, they expend a great deal of power, hundreds of watts in fact, rendering them infeasible.

High Pressure Sodium: Like the metal halide mentioned previously, the high-pressure sodium is also widely utilized amongst many growers. The output of light is generated mostly in the red-orange range of the spectrum, which is

conducive to the flowering stage of plants and not vegetation. The high-pressure sodium lasts longer than the high intensity discharge, 24,000 hours and 15,000 hours on average, respectively. The prices of both these options are comparable, starting at ~$15. Similar to the HID, the prohibitively high power expenditure is an issue with this lamp.

Regarding the previous light types just mentioned, there are many bulb types to choose from, ranging in quality, product lifetime and price. The group decided to select a light marketed for the purpose of growing plants. The following synopsis serves as a description of the bulbs we found particularly amenable to this project. All of these choices were offered from online vendors. Because of the great power expenditure of High Pressure Sodium and High Intensity Discharge, we decided to avoid these bulb types. We are cognizant of the heat the lighting fixture generates, it is important that the heat generated from the lighting fixture does not damage the plant. Therefore the bulb selected does meet the specifications that highlight its generation of the needed amount of light while expending minimum power and producing a negligible amount of heat would be ideal. Dependent on these factors was the distance the light may be placed from the plant. If the light expends a great deal of power, produces excessive heat and generates little light, placing the grow light closer to the plant would jeopardize its survival. For this reason, we also decided not to use halogen bulbs. The resulting choices are either LED or CFL bulbs. Elaboration of their advantages and weaknesses are provided in the following:

Miracle LED Grow Light 605020, Red Blue: Emanating 200 lumens with a color temperature of 2000K for 30000 hours, the Miracle LED Grow Light was least expensive option we encountered. This represents a viable option compared to the others because it includes only what we need at a very reasonable price. It also supplies Red and Blue light and offers the familiar E26 base provides convenience. A variation of this fixture, also from Miracle LED is the absolute spectrum grow light, which is similar to sunlight. With a 5000K color temperature and a medium screw E26 base for $16, this option seems even more promising. Both contain a parabolic reflector that bolsters light distribution at the expense of size.

21 Watt par30 LED Grow Spot Light Bulb: This $60 light supplies 550 lumens with a 40000-hour life expectancy. It provides red and blue color combinations at 21 watts. The fixture contains a parabolic reflector and it features the familiar screw mount threaded base (Edison E26 base). While these features seem impressive, we may consider other, less expensive options.

Bloomboss Spot LED Grow Light: With an operating lifetime of 50000 hours and a coverage of four square feet when the bulb is 6 to 8 inches from the plant. It radiates both blue and red color temperatures. This fixture is only half a pound and the power consumption is only 12 watts. These attractive features require a hefty price tag of $70, which is likely too expensive for this project.

MicroGlow LED: With a low power expenditure of 12 watts, a power factor of > 0.97 and an operating voltage of 85 to 264 VAC the MicroGlow LED does not pose any issue regarding power consumption. It also offers a Red/Blue color ratio of 9:3. The fixture is one pound and the working temperature is 68oF to 104oF. However, the $40 price tag indicates there are better options.

60 Watt CFL Grow Light Bulb 5500K H60: The 60 watt Compact Fluorescent Bulb emits a respectable color temperature of 5500K. We prefer an LED but this bulb offers a full spectrum output for just $12. The dimensions are 8x3x3, which may be too large for the space occupied by the plant. The CFL bulbs contain toxic mercury that may contaminate the plant if the enclosure falls over due to inclement weather.

Bulbrite 860196 Plant Grow Light, Dimmable: Despite mentioning the vast amount of limitation associated with the incandescent bulbs, they are dimmable at a low cost (starting at $30). The other bulb types that are designed for plants offer this feature at a very high price, starting at $80. We considered the Bulbrite incandescent bulb based on that feature. However since it only lasts 2000 hours and consumes 50 watts, it may not be worth it and we may select an LED bulb instead.

3.4.4 Photo Sensor

Selection of the photo sensor required the knowledge of the plants absorption spectrum explained previously. Regarding the photoperiodic nature of plants, the sensor is to activate the lighting assembly in the absence of a certain amount of light, with the exception of night and only during the day, a condition that has been programmed into our controller. Among the relevant criteria we considered important to our project were range of spectral bandwidth, peak sensitivity, what voltage and current it would generate when activated and the packaging. Most photo sensors possess a spectral bandwidth of 440 to 800nm which account for the range humans and plants perceive; (400 to 700nm) and (430 to 662nm, 453 to 642nm) respectively.

Different Photo-sensors operate by different modalities; the most common types are the photoelectric cell, photodiode and phototransistor. According to ROHM Semiconductor, the photoelectric cell detects a range of light that is detectable to the human eye. The photodiode has a low output current and the phototransistor creates a larger output current. Consequently the phototransistor is much more sensitive as it generates more current per photon absorbed on its surface. Not surprisingly, in terms of semiconductor physics, the phototransistor is slower compared to the photodiode. Despite the greater sensitivity of the phototransistor, the signal to noise ratio is lower than that of the photodiode. The phototransistor is more susceptible to noise due to the effect of thermal voltage on transistor function. Since sensor speed is not a concern for this project but sensitivity is, the phototransistor seems more promising than the photodiode.

Well, since the temperature of the environment the sensor is placed in may reach a large values and the thermal voltage from the transistor generates a fair amount of noise, it might be wise for us to consider the less sensitive photodiode, even if we do not need the extra speed that accompanies it. What we must determine is if the noise generated by the phototransistor in the presence of high temperatures is so great that it would create unacceptable error, prohibiting the use of the phototransistors. For this device, noise and speed of our sensors is not a concern since the growth of plants is very gradual. Consequently, the group selected a transistor rather than a diode for these reasons. The device is the TEPT 5700 photo detector from Vishay Semiconductors. This $0.62 NPN phototransistor is available in a T-1 package. The peak sensitivity is 570 nm and the power dissipation has a maximum rating of 100 mW.

3.5 Power Distribution and Regulation System

This section involves the research of power devices, which consist of a photovoltaic (PV) array, inverter and battery, the load requirements has been rated at +12 VDC, -12VDC, 5VDC, 3.3VDC. The theory of operation of the inverter will be briefly discussed in order specify a quality product for the design effort. A PV controller device will be discussed and how this device needs to be integrated into the system.

3.5.1 Photovoltaic System

There are two types of Photovoltaic systems. They are the grid-direct system and the battery-based system. The value of having a grid-based system is that there are fewer components to deal with in the design effort and therefore more cost effective. The systems effective energy output is greater than a battery-based system. The maintenance requirements are less. This is a good system if the load requirement is at say 50%, then the other 50% can count as credit to the utility provider. Special approval and a commissioning process are required which is an additional downside to this application. The battery based system can be utility-interactive or a stand-alone configuration. These two systems are very similar except for the inverter requirement. There is an anti-islanding provision that will be explained. When there is a utility outage or brownout condition the inverter needs to sense this occurrence and immediately disconnect itself from the power system. If the inverter did not have anti-islanding specification, power would still be sent back to the grid and thus provide a potential shock hazard to utility workers. This project uses the battery-based stand-alone system due to cost of material, lower maintenance and less government regulation. The important aspect to note in this type of design is the load requirement, which influences the quantity of batteries required. This project uses one battery with the capability of using a secondary battery if required. Another important aspect is that batteries require monitoring and maintenance. This system consists of a solar array, charge controller, battery bank, and power distribution network.

The system's energy requirements have been estimated. After the requirement of wattage is determined from a photovoltaic array or the wattage consumption of

each of the loads is determined, these values are used to determine the overall consumption rate. The key objective is the production or consumption in Watt-hours (Wh). This requires the number of hours the PV has been operating or how long the various loads has been in use. The energy quantity needed is the time value multiplied by the power draw.

$$Energy\ (Wh)\ =\ Power\ (W)\ x\ Number\ of\ hours.$$

For example if the PV array is rated at 1000 watts and the sun is present for 7 hours, then the energy output will be the following:

$$1000W\ x\ 7hours\ =\ 7\ kilowatt-hours\ (kWh)$$

Since a battery system is being used, the batteries are rated by value of amp-hours (Ah) since the objective is current flow.

$$Amp-hours\ (Ah)\ =\ Amps\ (A)\ x\ Hours$$

To convert the Watt-hours to Amp hours, just divide the Watt-hours by the applied voltage to achieve the conversion.

3.5.1.1 Photovoltaic (PV)/Solar Panel Array

The solar panel acquires energy during daylight conditions and store energy in reserve for use during dusk. A current limiting device needs to be incorporated so the battery system doesn't get overcharged. Utilizing a prefabricated solar array versus doing assembly in-house of a custom array is realized with time versus budget concerns. Most solar arrays for sale are meant for residential housing or commercial business. These units are usually installed on rooftops or elevated structures with a large surface area. Those applications would be too extreme for this project. Individual mono crystalline silicon panel PV cells are at 24% efficiency but full panels assemblies are only up to 18% efficient. The individual theoretical limit is at 27%. Solar energy efficiency is not similar with other energy sources but this gap is closing according to the National Renewable Energy Laboratory. With the efficiency of PV cell between 13.5% - 18% solar power is becoming more popular. Government subsidies have motivational factors as well. Utility provided power is still more cost effective than solar power if your dwelling is less than a mile from a power plant.

A series connection of individual PV cells consists of connecting the positive lead of one cell to the negative lead of another cell. The industry term for this process is "stringing the modules together." The series of strings of course start with two but the maximum PV count has restrictions set by the NEC. This project's design only requires a theoretical count of nine (9 x 1.5v = 13.5v) and this is within the limits of the NEC requirement. The series connection of PVs results in having the voltage values summed and the current values remain the same. This configuration is analogous to battery configuration in a facility UPS system. With the NEC limit on the PV cell count of a "string", parallel connections are made to create more power. To make this configuration, the positive lead of one "string" is connected to the positive lead of the next "string" and this is repeated for the negative leads. This configuration depicts a series-parallel system.

Solar radiation describes the energy that is sent to the earth from the sun. The concepts of solar radiation are critical since this is the energy being transferred on all Photovoltaic systems. There are two categories of solar radiation and these are direct radiation and diffused radiation. The amount of radiation is dependent on regional atmospheric conditions. On a clear sunny day, radiation levels are close to maximum levels, and of course on cloudy days this level is reduced or diffused. Direct radiation makes the greatest contribution to a solar array and result in the greatest effect of desired power transfer. Clouds or water vapor, dust, and other airborne particles divert the sun's diffuse radiation. Albedo radiation or reflectance is produced around the PV collector site. The light is reflected from physical surroundings such as the roof of a building, or a body of water, and rerouted back into the atmosphere as diffuse radiation. All the scenarios explain why it is critical to have the solar array system normal to the direction of the sun for maximum realized energy transfer.

3.5.1.2 Activation/Deactivation

A DC controller and noise reduction design has been used for the project's photovoltaic (PV) controller. The current capacity can be increased from the original 2amp design. The components affected are likely be the power transistors. The activation/deactivation as shown in Figure 5.5.1.2-1 is used so the battery does not discharge into the Photovoltaic system. Total voltage of the Photovoltaic cells should be greater than the battery voltage. This allows for line loss and voltage drop across the limiting diode. This Figure is a simplified system block diagram that represents the PV controller's critical function. The block diagram below in Figure 3.5.1.2-1 illustrates the Solar Array/Battery configuration.
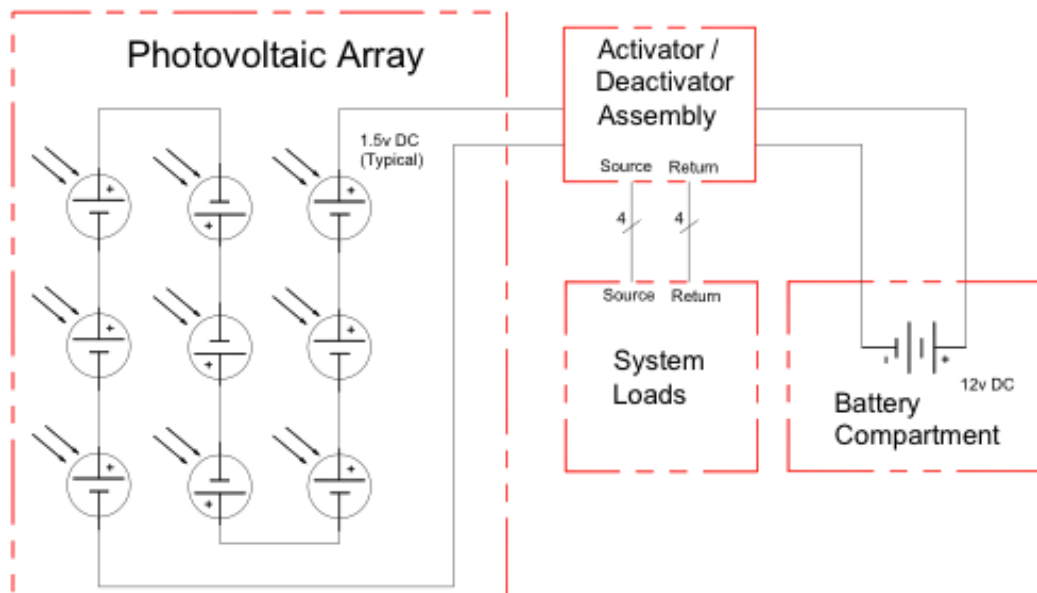

Figure 3.5.1.2-1;
Photovoltaic Power Supply Block Diagram
(This illustration was drawn using AutoCAD educational software.)

3.5.1.3 Battery

A 12-volt battery of 20amp hours (Lithium Ion) is used to store the energy from the solar array during daylight hours. An optional second battery design can be implemented as an additional AC rectifier filter component. This needs to be evaluated if budget is marginal.

A typical battery cell has 1.5 volts across its terminals. The current and voltage capabilities depend on the size and chemical properties of the cell. The positive terminal/cathode and the negative terminal/anode describe the fundamental make-up of a battery. With other devices such as capacitors, vacuum tubes, and silicone diodes the anode and cathode configuration are opposite.

"Some cells are designed to provide high open-circuit voltages, whereas others are designed to provide large current capacities." "Certain kinds of cells are designed for light-current, intermittent applications, whereas others are designed for heavy current, continuous-use applications." The ambient weather station is most likely be the only block item that is be in continuous use for long periods. The duty cycle for the remaining blocks is at approximately 50% or less.

Batteries that are designed for use without recharging are called "primary batteries." Batteries in this category are carbon-zinc batteries. Once the energy is used up in a primary battery, they are thrown away. These types of batteries are not be used since this project is based on a "reusable energy" design.

Secondary batteries are rechargeable. This is a good specification to have for reusable energy. The discharge specifications for secondary batteries are similar to primary batteries. The optimum characteristics of secondary batteries are their long operation life and high power discharges. This characteristic is the opposite for primary batteries. Secondary batteries are more robust in design but also more expensive as well.

In a full-scaled application of this project, a deep cycle lead acid battery system is preferred and mentioned in household marketing configurations. The major use of the lead acid battery is in small and large combustion engine applications, which require high power draw and the commercial usage "cold cranking amps". This scaled down version of a greenhouse system uses a Li-Ion battery though. On the periodic Table of Elements, Lithium is the lightest of alkali metals and also has the highest electrochemical potential. With this being said Lithium has an extremely high energy density. The down side is that the metal itself is very reactive. This is a problem with rechargeable batteries and thus precautions must be observed and adhered to. The "explosion risk" requires appropriate protection in order to avoid puncturing the battery during transport. See section Transport Assembly 4.4 Li-Ion batteries have about twice the energy of NiCad batteries, making them the most compact rechargeable battery on the market.

3.5.1.4 Inverter

In this project a commercial off the shelf (COTS) unit is used to save man-hours on the project. No design involved here but specifications need to be analyzed for proposed units. Building and testing a unit from component level would not be cost effective either. The specification of a proposed unit still needs to be analyzed.

The Black & Decker Model PI750 AB has been considered. This power inverter is designed to convert a DC source to an AC waveform. In this design a single-phase current source inverter is used. A common home use inverter is rated at 750 watts with a maximum current flow at 6.52 amps. The output waveform is a modified sine wave at 60 Hertz 115 volts AC. The Black & Decker's circuitry is propriety but a more general description can be evaluated. A single-phase current source inverter circuit with capacitor commutation is shown in Figure 3.5.1.4-1 below:
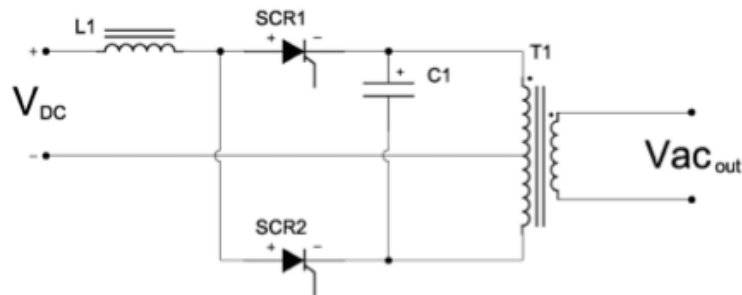

Figure 3.5.1.4-1; Basic Inverter
this illustration was drawn using AutoCAD educational software.

Its components are the two SCRs, a capacitor and an AC step-down transformer for the AC output. A temperature sensor near the outlet fans would be a good idea since this device can be susceptible to overheating. The modified sine wave inverters are simpler in design and the result is a "stepped" sine wave output. The modified output can operate most standard electrical applications. This item is more portable than a pure sine wave device. This modified sine wave should not present a problem for the irrigation pumps.

Pure sine wave inverters are the "high end" of the inverter product line. This device is the most reliable and provides a smoother sine wave. This item is more expensive but would be essential for devices that require critical service. The use of inverters in moist areas causes the drivers to burn out. A good tip is not to use wet power cords. This is used for the function of a utility outlet. Test equipment such as an oscilloscope, spectrum analyzer, and logic analyzers that require an AC power source.

3.5.1.5 Uninterrupted Power Supply (UPS) Operation

This circuitry provides uninterrupted power to the system in the event that the photovoltaic cells are not charging to the system and the batteries and if the battery output has been depleted. In a household operation commercial power is the primary source and the battery is a secondary back-up device. In this project the solar/battery power is the primary source with commercial power in reserve.

The first phase of the power supply design is the step down isolation transformer. An AC voltage is feed to the primary coil of a transformer, and thus a magnetic flux propagates through the iron core and induces a reduced voltage at the secondary coil. The transfer of electrical energy to magnetic energy and back to electrical energy has occurred. The magnetic flux just mentioned is why metallic enclosures are used in power supplies. The transformer voltage ratio is represented by the following formula:

$$Vs = Vp \; x \; \left[\frac{Ns}{Np}\right]$$

Therefore if N_p > N_s then V_s < V_p. This representation reflects this project's transformer application. A full wave bridge rectifier module with the desired power capacity needs to be initially de-rated to 60% in order to allow for start-up over-shoot and future expansion of the whole system. A robust filter design needs to be incorporated in the rectifier subassembly. The filter design should solve two requirements that the first is to establish a slow discharge rate when transitioning from commercial power to solar power. The second is the reduction of DC ripple for optimum CPU operation. Design methods can be employed to allow for voltages with opposite polarities. In Figure 3.5.1.6-1 there is a design for a split supply design.
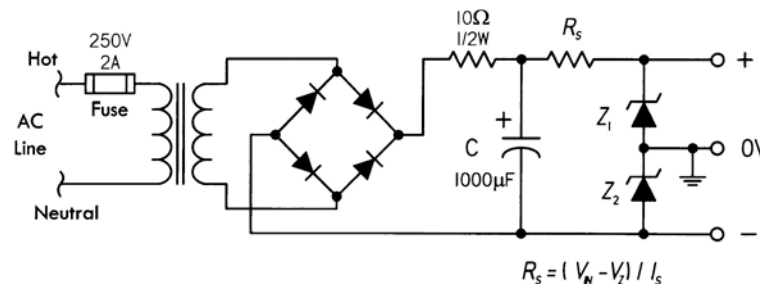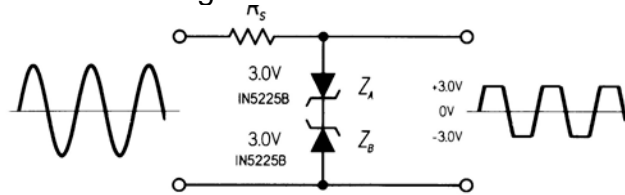

3.5.1.6-1; Split Supply from Single Transformer Winding
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(Monk, 2013)

A method for producing a split supply from a transformer without a center tap is described using two zener diodes. Thus two zener diodes, Z1, and Z2, of the same voltage and power level for specified split voltage and load, are configured as shown in the Figure above. Temperature effects these zener diodes' operation making them less accurate than a supply that uses two separate regulator IC chips. This is a simple application for noncritical circuits though.

This type of design might be needed for unexpected reverse polarity voltage requirements in the prototype. There is not currently any planned application for voltages with reverse polarity.

Figure 3.5.1.6-2 illustrates a design for a waveform limiter.

Figure 3.5.1.6-2; Waveform Modifier and Limiter
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PRACTICAL ELECTRONICS for INVENTORS.
(Monk, 2013)

Two zener diodes with opposing polarities clip the peak levels of an input signal. As a result a sine wave is transformed to a rough square wave formation. In addition to reshaping a waveform, this configuration can also be installed across the output of a DC power supply. This is to prevent unwanted voltage transients or spikes from reaching a connected load. The breakdown voltages for the zener diodes must be greater than the supply voltage, but also smaller than the predicted maximum transient voltage.

The circuitry can be employed in the project but it would be preferable to specify diodes that doesl not cut off the sine wave and thus result in a square wave. This limiter could be used in the stepper motor application.

Figure 3.5.1.6-3 presents a voltage booster.
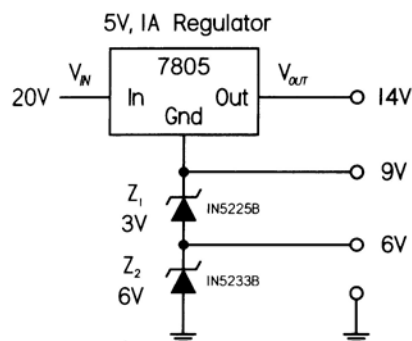
Figure 3.5.1.6-3; Volage Regulator
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(Monk, 2013)

Zener diodes can also be used to increase the level of a voltage regulator and supply different regulated voltage outputs. For example 3-V and 6-V zener

diodes are placed in series to raise the reference ground of a 5V regulator IC up 9V and obtain a total value of 14V. Filtering capacitor placement may be required at the regulator input and output of most practical designs. This similar design can be employed in the Activator/Deactivator or PV controller circuitry in the design. A Crow-bar circuit which is utilized in Lambda power supplies is an option. Simple applications are circuit breakers and fuses.

3.6 Enclosure

The housing or "enclosure" of the device is actually divided into three primary areas; the grow area of the plant, the irrigation reservoir and the electronics compartment. The reservoir, electronics compartment and grow area must be maintained at optimal temperatures and this is a function of the heat resistance of the material from which the enclosure is constructed. Humidity is also a concern in the electronics compartment as well. The weight of the enclosure contributes predominantly to the total weight of the device, so in addition to heat resistance, lightweight cost effective materials have also be investigated. Consequently the items related to the enclosure the group has researched include characteristics of various material types, cooling fans, sealants and gaskets, dehumidifiers and humidity sensors. The following sections elaborate on our research.

There are many arrangements under consideration that would ideally provide ease of access to the irrigation reservoir and to the electronics area while eliminating or reducing the effects of humidity generated from the reservoir as well as ambient conditions. The group intends to separate the compartments of the enclosure so the electronics area and the reservoir do not share the same space. This presents a complication however, because this arrangement would increase fabrication costs from the vendor due to the variation in design. Electrical components must be resistant to the effects of humidity to circumvent any potential issues that might be encountered by weatherproofing the enclosure.

The material that the enclosure is made of would ideally be lightweight, safe for the plant and have a high specific heat capacity. The specific heat capacity (measured in units of joules per the product of kilogram and kelvin) is the required energy needed to raise the temperature of a material by one degree. More heat needed to raise the temperature would mean that the material possesses greater heat resistance. The water in the irrigation system, the electronics, and the plant itself must not be exposed to large temperatures, so the specific heat capacity of the enclosure material should be as large as possible. The optimal water temperature for photosynthesis is about room temperature (2^oC), with a margin of +/-6^oC. Temperatures that are too warm or too cold may damage roots and diminish nutrient uptake. The enclosed area the reservoir occupies in the warm Florida climate is more prone to large temperatures so a heat resistant material with a large specific heat volume is desired.

The material must be resilient and resistant to harsh weather conditions. Regarding durability of the enclosure, the hardness of a material is also a concern. The Rockwell Hardness Scale measures the hardness of a material based on certain classes, with a larger value corresponding to greater hardness. A value of R70-R100 is under consideration for this material specification. This value should ensure enclosure durability but not rigidity. Density (mass/volume) also contributes to our material consideration; its value is related to weight and complete device should weigh less than ten pounds, ensuring ease and portability of the device. The combined weight of all components will be addressed later in the design area.

There are many types of materials to select from that satisfy such criteria. In addition to the material attributes just mentioned, cost was another factor that contributed to our selection. Our choice of material is also dependent on the materials the fabrication houses work with, so it must be chosen to fit their constraints. Among the options under consideration include the following:

- *Polypropylene* - The density of this material is 0.9 (g/m^3) and the specific heat capacity is 1.7 to 1.9 (JK^-1Kg^-1). The hardness according to the Rockwell Index is R80 to R100.
- *Polycarbonate* - The density of polycarbonate is 1.20 to 1.22 (g/m^3) and the specific heat capacity is 1200 to 1300 (JK^{-1}Kg^{-1}). The hardness according to the Rockwell Index is M70. Compared to Plexiglas, this option is more expensive.
- *Polyethylene* - The specific heat capacity of polyethylene is 1.85 J/(Kg*K)). The density is 0.88 to 0.91 (g/cm^3), although there are many different types of polyethylene and the density varies across a very broad spectrum.
- *Polymethylmethacrylate (Plexiglas)* - The specific heat capacity of Plexiglas is 1400 to 1500 (JK^{-1}Kg^{-1}), the density is 1.19 g/cm^3 and the hardness, according to the Rockwell Scale is M92 to M100. This option represents a cost effective solution since it is the least expensive.
- Polyvinyl Chloride (PVC) - Is the most well-known, as it is the material of plastic pipes and other items. The specific heat capacity of this substance is 1.2 J/(K$_g$*K)), the density is 1.26 g/cm^3.

There is also a number of fabrication houses that specialize in rapid prototyping, CNC routing and injection molding. This enclosure is very basic, yet it requires a customized design. Another option would be to simply purchase premade shapes of plastic and snap the pieces together but that would make our device have a shoddy appearance. With this in mind, there should be anticipated fabrication costs to be prohibitively high but nevertheless expense certainly factors into the selection of the vendor. If the price quote exceeds the cost in our budget there are options to purchase enclosure pieces from a vendor such as Eagle and not to have it custom molded. Fortunately, there are many vendors who specialize in this type of work for a reasonable price. Because the needed design of each

customer is different, the actual price is rarely displayed on the website, and it requires quotes from each company. Another option would be to enlist the services of a local company in the Central Florida area to avoid the high cost that would otherwise incur for shipping the enclosure. Some local companies under consideration are Custom Plastic Development, Inc., 7Plastics, Inc, and Nylacarb Corporation, among others. During the prototyping phase, these companies may be contacted to request quotes for a custom fabrication.

The frame is not the only issue regarding the enclosure, but also the appropriate brackets, flanges, fasteners, fittings and gaskets to hold the irrigation tubes and the electrical equipment, including the wires, in place. This part of the design may seem trivial; however, a stray wire that is not fastened to the inner wall of the enclosure causes that wire to be vulnerable to damage and also represents a safety hazard. The material of the enclosure that is selected does not affect the process of adjoining these items to the frame. Drilling and gluing these components into as well as onto the enclosure have achieve this. These components are not expected to contribute materially to the cost of the project and they can be purchased at any local hardware store.

Humidity is a measure of the water vapor in the air. Warm air possesses much more energy than cooler air, imparting the energy needed to allow the standing water to evaporate and vaporize into the air. Too much humidity may damage electronics, especially when the temperature increases or equivalently for this example, when the device is transferred from a cooler environment to a warmer environment. Such a temperature change causes condensation; the water vapor in the warm air condenses on the cooler surface, making the surface moist. Obviously, regarding the electronic compartment, this prospect poses several issues; the parts may rust, corrode, a short may be created, etc. Too little humidity is also a problem for the equipment, making the components brittle; but that is not expected to be an issue for our project. Excess humidity is a major issue with our enclosure because of the proximity of the water reservoir to the electronic cabinet. No matter how the irrigation system is sealed, the inevitable possibility of water vapor of reaching the electronic area persists. Maintaining a humidity level of ~45% is the ideal. Regardless, the electronics compartment is to be maintained at a lower humidity than the plants environment. One solution utilizes a fan to mitigate the effects of such humidity. Ventilating the inner electronic compartment from the external environment reduces the humidity, but only if the external environments humidity is lower. An electric dehumidifier could be purchased for a reasonable price (~$40) however, this seems like a convenience rather than a resourceful solution and it may not even be needed.

Another consideration is to purchase a hygrometer to measure humidity. The sensor would occupy the same compartment as the microcontroller and the power system. Such proximity would facilitate the hygrometers connection to the controller. Like the pH sensor, the hygrometer is not designed to interface with a microcontroller. The issue arises in taking the sensor device apart, determining

the signal path, splicing the wire carrying the signal from the sensor and connecting it to the pin of the controller. Ostensibly, the variance of the voltage level of the sensor signal would correspond to a relative spectrum of humidity. The microcontroller would receive this voltage level and process the humidity value with an algorithm built into the controllers program. Conditions have been installed into the controller to detect acceptable and hazardous humidity levels, with the latter resulting in the activation of a fan, the opening of vents of the enclosure or some action that would result in the reduction of the ambient humidity.

One promising solution that may eliminate the need for a hygrometer would be Eva-Dry E-333 9993 Dehumidifier. Utilizing silica gel to remove moisture, this device does not need a battery or electricity to operate, unlike a conventional dehumidifier. Instead, the silica gel absorbs the humidity. The silica gel possesses a large surface area with high porosity that facilitates the absorption of water vapor. For this reason, the silica gel is a desiccant; a substance that absorbs moisture. One is reminded of the small silica gel packets that are included in the boxes of furniture, appliances and other goods. With length, width and height dimensions of 6inches x 1inch x 5inches, respectively, the product also conforms well to the enclosure design. Indeed, the product was especially designed for enclosed cabinet spaces and can absorb about 6 ounces of water over a period of a month, just what this project needs. The suitability of this option becomes even more apparent when one considers the reasonable $25 price tag.

 In addition to humidity, the electronics compartment needs proper cooling as well. The pertinence of this issue becomes clear when one considers that the compartment is enclosed in the warm Florida weather. After researching many fans, the group agreed that a computer fan was the best option. These fans share many similar specifications; the primary specifications are the size, the noise they generate within a certain environment (which is measured in units of dBA) and the number of revolutions per minute of the blade (a larger RPM value is preferred for cooling). Price is also a factor, as spending more than $15 on this utilitarian item is not necessary. The group was not concerned with the dBA value, since the device operates autonomously and does not require the presence of human. Therefore, the environmental noise rating was not a concern. The size is concern since the enclosure should be made to be as small as possible. With this concern in mind, the group considered two options, the StarTech FAN6X1TX3 for $6 that operates at 4000RPM and is 60mm or the $13 Antec TrueQuiet 120mm, two speed fan with a maximum speed of 1000RPM. Unlike the StarTech model, the TrueQuiet is included with mounting grommets but the StarTech model is smaller and generates more RPM.

3.6.1 Greenhouse
A greenhouse surface that would be connected on top of the enclosure is under consideration. The material of the greenhouse may be considered a photo filter

as it passes light of certain frequencies and wavelengths and rejects other wavelengths and frequencies. The upshot of this enclosure is the generation and entrapment of thermal radiation or heat. The mechanism works when the surface of the glass passes short wave, infrared radiation. The plants and interior of the greenhouse which are exposed to the incident light generate invisible long wave infrared radiation, this radiation propagates back up to the surface of the greenhouse causing the surface to emit additional long wave infrared radiation, creating and trapping additional heat. The best material for a greenhouse enclosure is glass. However glass is very expensive; the mounting and custom fabrication of this heavy material entails considerable work and expense. The group is considering polyethylene film that is actually a sheet of plastic and not a rigid material. Pieces of this inexpensive alternative can be cut with scissors and formed into the needed shapes. This sheet is available from growerssolution.com for $58.

If a greenhouse enclosure is selected, proper ventilation is needed to curtail excess humidity and to eliminate the potential accumulation of pathogens that would undermine the growth of plants, so adequate air circulation is needed. Vents in the greenhouse may implement air circulation, such that when a controller interprets a signal from a sensor that is processed as a hazard, a motor is activated to open the vents. A fan may also be implemented to facilitate circulation but its addition is pending due to the prototypes small size; the natural draft of the external environment may be sufficient for circulation. If the group decides to use a fan that would be activated by the controller, the StarTech FAN6X1TX3 for $6 is the most likely option.

3.7 Microcontroller
The microcontroller is a vital component to the overall project since it shall be acting as the brains of the entire system. The autonomous behavior of PASS shall be coordinated by the microprocessor via data collection and analysis from the connected sensors. The market for microcontrollers has grown over the recent years, so there are a large number of options available at competitive specs and prices. The key aspects for this project under consideration include the pin count, power consumption, clock rate, and memory specs, analog to digital conversion capabilities, size, and the potential development difficulties.

3.7.1 Proposed Products
Atmel ATmega328P: The first microcontroller taken under consideration was the ATmega328P designed and manufactured by Atmel. This is an 8-bit RISC-based 32-pin single chip controller with a modified Harvard architecture. It utilizes on chip 32KB flash memory, 1024B EEPROM and 2KB SRAM to store instructions and data in distinct memories. This high performance microcontroller operates at a maximum 20 MHz frequency with an internal oscillator and multiple power saving modes. This device has a total of 23 I/O pins. This includes 14 digital I/O pins, which six of these can be used as pulse width modulation (PWM) channels. Another 6 pins are utilized as analog input. Some additional peripheral features

include a programmable serial USART, I^{2}C compatible serial interface, and an on-chip analog comparator.

The ATmega328P has an operating voltage between 1.8-5.5V and a temperature range of -40°C to 85°C. The system comes with six sleep modes and power-on reset functionality. This MCU has a potential to produce a throughput of up to 1 MIPS per 1 MHz all a byproduct of an architecture that is more code efficient compared to conventional CISC microcontrollers. This particular Atmel microcontroller also supports a real Read-While-Write Self-programming mechanism.

This microcontroller is the dedicated device of the Arduino Uno development board. Arduino is a user-friendly development kit that takes some of the "messy" details from microprocessor programming. Arduino is an open source project that is available for use on Windows, Macintosh OSX, and Linux operating systems. Since it is an open source software project and from its popularity among hobbyists and developers, a large community has grown. So there is a large quantity of support and tutorials available, which provides for an excellent product for inexperienced users that are learning about microcontrollers.

Texas Instruments MSP430: The Texas Instrument MSP430 family of microcontrollers contains many devices each with a different set of features targeting an assortment of applications. These devices offer a 16-bit RISC single-chip controller with Von-Neumann architecture. The memory hierarchy consists of up to 16KB flash and up to 512B of SRAM. There are a total of 24 I/O pins, of which at least 8 are digital I/O. Each MCU in the MSP430 family also comes with a single hardware module called the Universal Serial Interface (USI). The USI component provides synchronous serial communication and it provides built-in hardware functionality to support SPI and I2C protocols. It also supports an enhanced UART with automatic baud rate detection.

The set of MSP430 devices were designed with ultra-low power consumption in mind and each one has a low supply voltage range between 1.8V to 3.6V DC. There are also a few different package options including a 20-pin thin-shrink small outline integrated circuit, 20-pin plastic dual-in line, and a 32-pin quad-flat no-leads package. Some additional features include an analog comparator, 10-bit analog-to-digital converters, and a watchdog timer for controlling system restarts due to software problems. Another consideration of the MSP430 controllers is that the Embedded Applications course at UCF has been utilizing them as the main lab component, so a majority of the members of this group have previous experiences with them.

Microchip PIC24H/E: The PIC24H/E family is Microchip's high performance 16-bit microcontroller with a modified Harvard architecture. The memory options for this controller include up to 536KB Flash for program code, 48KB for data, and 4KB for Direct Memory Access (DMA) RAM. The DMA component of these microcontrollers allow for data transfers between RAM and a peripheral while the

processor is executing code. These devices come with up to 85 I/O pins including 2 UART, 2 SPI, and 2 I2C digital communication peripherals.

These microcontrollers operate between 3.0-3.6V DC with a temperature range of -40°C to 85°C. The software development is completed in a C –like optimized instruction set and there are 71 base instructions. The PIC24H/E class also has a 2.5V voltage regulator along with a few power management modes including idle, sleep, and doze. This class of MCUs is provided in thin quad flat pack (TQFP) packaging. Some additional features include up to two analog-to-digital converters, up to nine 16-bit timers, and an interrupt controller with seven programmable priority levels.

3.7.2 Wired Communication

As briefly mentioned earlier, one of the major components needed for the microcontroller for the PASS is a method of data transmission within the PCB level. Most modern microcontrollers have some form of hardware for serial communications, which is when a single bit is transferred at a time. An alternative to using dedicated hardware would be to implement a form of data transmission by having software control output pins of the device. This is also referred to as bit banging. Communication techniques can be broken into two general categories: synchronous and asynchronous. The first term is referring to the fact that data is sent following a clock signal, whereas the latter sends data without a clock. In the following subsections, an overview of some of the more common wired communication systems found on microcontrollers will be covered.

3.7.2.1 Serial Peripheral Interface (SPI)

Motorola developed this communication protocol and it has been used in a wide range of applications due to its simple implementation requirements. SPI provides digital synchronous communication with a master and slave design. The master provides clock signal for both devices and initiates data transmission. Overall there is a total of four connections plus a ground wire. These connections include a clock signal and a signal to select or turn on the slave device. The other two data lines called master out, slave in (MOSI) and master in, slave out (MISO). These lines are one-way connections for the master to slave and slave to master, respectively. This design leads to SPI as being full duplex meaning that data can be transmitted simultaneously in both directions between the master and slave. This also leads to faster data transfer due to the parallel transmission. One negative side of SPI is the fact that there is no official standard so each manufacturer has their own flavor of the protocol and this must be considered when using this protocol.

3.7.2.2 Inter-Integrated (I^{2}C)

Another common synchronous serial communication protocol implemented in modern microcontrollers is the Inter-Integrated Circuit bus or I^{2}C. This protocol is also occasionally referred to as the two-wire interface since it is composed of two bidirectional lines for data transmission (a third wire is required for ground).

These two connections are for serial data and the serial clock. One immediate benefit from this design is the decrease in footprint since there are fewer lines compared to a similar protocol such as SPI. This forces the connection to be half-duplex which refers to the fact that data must flow in a single direction during each clock cycle. So overall the saving in pins leads to a decrease in data transmission rate, which is usually around 100Kbps.

The overall design of I^2C follows a master-slave communication protocol similar to SPI protocol. The I^2C protocol can be easily extended to a single master with multiple slaves. There is a need for some type of controlling mechanism, either in hardware or software, to coordinate when to transmit data between devices since the data lines are bidirectional.

3.7.2.3 Universal Asynchronous Receiver/Transmitter (UART)

The Universal Asynchronous Receiver/Transmitter or frequently referred to as UART is a common serial I/O module implemented in microcontrollers. It is a full duplex, asynchronous communication component to transmit serial bit streams between devices. This interface can also be modified to support half duplex, receive only or transmit only. Over the long history of UART, many different physical and protocol layers have been developed including RS-423, MIDI, and IrDA. In order to support this variety of connections, UART is configurable with regards to number of data bits, hardware flow control, and parity. Overall a UART converts data between serial and parallel forms by transmitting/receiving the least significant bit up to a set of stop bits.

3.7.3 Wireless Communication

A form of networking needs to be implemented in order to provide a communication between the base units of the system with an external device, such as a tablet. This smart mobile device has been utilized to provide information about the plant and PASS system as feedback to the user. A wireless network has some distinct advantages over a wired infrastructure and those ideas fit well with the requirements and objectives of this project. Minimizing the presence of wires and electrical components is a priority for PASS in order to hide the technical aspects of the device from the user. Another key aspect is for the user to have easy access to information about their plant and overall system. A wireless network makes this achievable by allowing any user to connect a mobile device with the PASS.

There are many different options available to achieve this and a few of the common wireless networking standards are highlighted in the following sections, but first let's discuss some wireless terms. One of those terms is spread spectrum, which is a set of techniques for sending a single radio signal using a wide range of the radio spectrum. These methods transmit radio signals by signal modulation by using ideas such as frequency division multiplexing. One such method is Orthogonal Frequency Division Multiplexing (OFDM). In this technique, the channel bandwidth is split into many subcarriers that send data at a

designated period so then when all the subcarriers are multiplexed into a channel there is no interference between them. Another commonly used method is the Direct-Sequence Spread Spectrum (DSSS) or referred to as Direct-Sequence Code Division Multiple Access (DS-CDMA). In DSSS, the signal containing the information is divided into small pieces by a bit sequence also called a chipping code because the small pieces of the original bit pattern are called chips. Overall spread spectrum techniques are used in communication systems that need a resistance to jamming and lower background noise.

3.7.3.1 Wi-Fi
The set of standards that consist of IEEE 802.11 are commonly referred to as Wi-Fi, which is one of the most popular wireless data services of today. There are three standards commonly used in the IEEE 802.11. The first is 802.11a, which has a frequency of 5 GHz and uses OFDM. Another Wi-Fi type is 802.11b and it transmits at 2.4 GHz with a DSSS modulation. The 802.11g is also a common standard and it combines the best of both 802.11a and 802.11b, which is a frequency band of 2.4 GHz with OFDM modulation. The ability to transmit information wirelessly is achieved via radio transmissions or infrared light.

The standards mentioned above utilize a spread spectrum radio, which has a wide band of frequencies and thus it is power efficient and less sensitive to interference from other signals and noise. The 802.11 protocols were designed to mirror the already existing wired local area networks (LAN). The 802.11a and 802.11g operate at about 54Mbps and the 802.11b at 11Mbps. These rates are able to support Internet connections. The distance between devices communicating via Wi-Fi is limited to around 100 feet indoors and 300 feet outdoors. A networking terminal acting as the transmission point for Wi-Fi signals must be implemented that transmits data between two devices.

3.7.3.1.1 Researched Products
WF111 Wi-Fi Module: The WF111 Wi-Fi module from Bluegiga technologies is $27 and features advanced Bluetooth support. This additional Bluetooth compatibility would work well for the group's project since it may confer compatibility with iOS devices as well as The Android OS. This module also offers 6 general-purpose I/O pins and features a transmitting power of 17dBm, which is comparable to the other modules considered. The data rate is 1Mbps and the operating voltage is 1.8 to 3.3 volts. The host interface it supports is SPI, UART, SDIO, and USB.

RN-171-XV Wi-Fi Module: The group considered the RN-171 families, from Roving Networks, which is rated with a sensitivity of -83dBm. The power consumption is 180 mA in active mode and 40 mA in idle mode. According to the specifications, the microcontroller is able to tolerate a relative humidity of 90%, which is desirable considering the conditions the device has been exposed to. At $38 dollars, this module is the most expensive of the groups Wi-Fi options and may provide additional features the group does not need. For example, this

module provides 8 general-purpose I/O pins that is more than the other options; however, the utilization of these additional ports is unlikely. The controller also offers 11 channels (which is actually the North American Standard) and each channel interval is 5MHz.

MRF24WBOMA Wi-Fi Module: With a measured sensitivity of -91dBm at its typical data rate of 1 Mbps and an operating supply voltage of 3.3 volts, the chances of using this surface mount module seem promising compared to those previously considered. Despite offering these desirable features, the $28 price tag is comparable with the other choices. A necessary receiving supply current is 85 mA and transmitting current is 154 mA. A major limitation of this module is that it is only compatible with SPI interface, not UART or USB modalities that we are considering. Since the group is considering UART as the host controller interface, the probability of selecting this module is low.

3.7.3.2 Bluetooth

Bluetooth is emerging rapidly as the leading mode in the formation of low power, short range, wireless that is categorized as an ad hoc network. This wireless data service was designed with intent to wirelessly connect a computer with peripherals like a keyboard and mouse. An extension of support for this protocol has been spread to cellular telephones and even automobiles. Bluetooth uses a FHSS modulation to move across 79 distinct frequencies 1,600 times per second in the 2.4 GHz range. Since this technology uses the same frequency range as the common Wi-Fi 802.11b and 802.11g services, there needs to be a form of coordination when both Bluetooth and Wi-Fi are active by the connecting hardware. This operates in the globally available, unlicensed, 2.4 GHz Industrial, Scientific and Medical (ISM) band. The Bluetooth protocol has to share the available frequency spectrum with IEEE 802.11b, which is the leading standard in Wireless Local Area Networks.

3.7.3.2.1 Researched Products

TI CC2564 Module: Texas Instrument produces a dual mode module that supports both classic Bluetooth and Bluetooth Low Energy (BLE). All of its features are fully compliant with the Bluetooth 4.0 standard. This component is capable of 4Mbps with operating voltage of 2.2 to 4.8V. This is great for this project since it provides a single solution to both the common Bluetooth connections. There are other devices in the CC256x family that can be considered that offer comparable specs with single mode operation, in other words it is only compatible with Bluetooth or BLE, but not both.

Bluetooth RN-41-N Class 1: For $24.95 this module boasts a data rate of 721Kbps to 2Mbps and supports USB, PWM and UART interface types. The operating voltage is 3.3 volts and a wide temperature tolerance of -40°C to 85°C, which is an advantage since our project has been subjected to outdoor temperatures.

3.7.3.3 ZigBee

ZigBee technology was developed to be a standards-based wireless service to focus on low-cost and low-power networking. This specification is based off the IEEE 802.15 standard and it is designed around extending battery life. ZigBee operates in the 2.4GHz frequency band across 16 channels. This wireless standard forms a mesh network topology with no central communication node, which is excellent for applications that may not have reliable connections. Information in this network flows between ZigBee compliant devices that can be classified as coordinators, routers, or end devices. Overall the mesh network is formulated by data being sent between all these devices via the routers as commanded by the ZigBee coordinator. This network technology can support up to around 200 feet indoors and 1200 feet outdoors. ZigBee has the data rate and the connection range to support a network with Internet access. Zigbee represents the standard while XBEE is the actual device that incorporates the standards. We consider employing the following XBEE modules based on their desired specifications for this project.

3.7.3.3.1 Researched Products

XStick USB Adapter Module: With a data transfer rate of 250kbps, a range of 66ft to 164ft and a sensitivity of   -90dBm, the $10 XStick USB adapter is a dongle like adapter. This seems like a promising option, however, a surface mount device may better satisfy the needs of our project. The group wants a dedicated device to be soldered onto the board.

XBee Series 2w/Wire: Boasting a range of 133ft to 400ft at just twenty-one dollars, the 2w/Wire series also has a sensitivity of -95dBm. Similar to other Xbee modules, the data transfer rate is 250 Kbps. The device has been exposed to a large temperature range, so a module that is capable to withstand such a range is needed. This module possesses an operating temperature of -40°C to 85°C. UART is the required interface type for this module. The controller we may select has a UART module, making this Xbee model an attractive choice for our project. A low output power of 2mW is also promising for this module.

XBee Series 2w/RPSMA: The difference between the 2w/Wire and the $30 2/RPSMA share many of the same specifications such as data sensitivity, operating range, output power, modulation technique and required interface. However, they differ in their antenna connector type; the 2w/Wire has a wire connector type and the 2w/RPSMA requires Reverse Polarity SubMiniature version A connection. RPSMA is a version of an SMA connector that is primarily used to prohibit users from connecting stronger antennas to the module, violating FCC rules. Ultimately, our choice depends on which connection is compatible with our controller choice

3.7.3.4 Z-Wave

In addition to the three standards above, Z-Wave is a wireless modality that is designed specifically for household appliances. Household automation is

evolving toward the capability that washing machines, dishwashers, alarms, etc. may communicate with each other and a centralized unit, furnishing runtime hours and status updates among many other applications for the homeowner. Since the PASS satisfies the criteria for a domestic application, the Z-Wave standard is an intriguing and appropriate wireless consideration for our project. Despite its relative obscurity, Z-Wave currently holds tremendous market share for home automation. Unlike the aforementioned standards, Z-Wave occupies the 908.42 MHz band. The following consists of our considerations that would be conducive to the design and function of our project.

3.7.3.4.1 Researched Products
ZM3102N2Wave Module: This $15 module shares specification values that define the Xbee devices. For example the sensitivity for the 2w/Wire is -95dBm while the ZM3102N has a sensitivity of -98dBm. Data transfer for the Z-Wave module is significantly less at 9.6Kbps/40Kbps than the 250Kbps value for the Xbee devices. For our project this may not be a problem if the Z-Wave module offers additional compatibility features that are conducive to the design of this project such as compatibility with iOS. Unfortunately, the research indicates that Z-Wave is not compatible with iOS.

3.7.3.5 Tri-Band Rubber Duck Antenna HG2458RD-SM
This antenna is designed to operate in three different bands of frequencies. The three bands are 2.4 – 2.5 GHz, 4.9 – 5.3 GHz, and 5.7 – 5.8 GHz. This would normally avoid the purchase of three separate antennas. Currently this project uses the 2.4 – 2.5 GHz frequency range for communicating with the Android user interface. The antenna is omnidirectional to allow for broad coverage of communication at 3dBi gain. This antenna filters out any interference or other frequencies not specified.

This device is 7.8 inches long and has a connector that swivels and tilt, which is handy for antenna adjustments at a right angle or other, desired angles for optimum gain. The antenna adjustment is not be too critical due to the omni-directional characteristics of this item compared to a "beam antenna". A beam antenna has better reception when the receiving antenna is pointed in the direction of the transmitting device. This component has an SMA male connector, which is a common connector for portable handheld radios. Obtaining an SMA female component for the microcontroller assembly should not be difficult.

This product should be considered if additional gain is required for the system. An example for this requirement would be areas of interference that would inhibit or completely jam communications or data transfer. This antenna can be used in conjunction with a set of different wireless technologies, including the ones mentioned in the above sections.

3.8 User Interface

There is an array of options with regards to the graphical user interface (GUI) of the PASS including, but not limited to external display on the base unit, wireless device, or even a webpage provided on the Internet. No matter the implementation decision of the interface there are some general features that must be present for it to be considered successful. These ideas include general robustness, flexibility, and friendliness to wide range of users. Overall this leads to a system that handles errors and faults gracefully with a logical and easy to use layout.

Taking into consideration these ideas along with the large workload that this project has already produced, developing additional external hardware for the interface was declined. The decision was made to go with developing an application for popular mobile devices such as Android and iOS platforms. The main objective of this part of the project is to provide the user with an application that can be downloaded to their mobile device, which directly communicates with PASS to share information about the overall system.

Application development for modern mobile devices can be achieved through a variety of tools and techniques. A large majority of the applications provided on the market are produced via software development kits (SDK), which are provided by the major mobile software device providers such as Apple and Google. There are a few other ways to produce portable applications as well. The following sections review the options of today's development tools to build a mobile application.

3.8.1 Android SDK

The initial development tool considered was the Android SDK, which is produced and maintained by Google. This development environment supports the creation and production of mobile applications for the popular Android platform that resides on a variety of tablets and phones. Android is open source, which refers to the fact that the entire framework is open for development by anyone without any licensing agreements. There are more than 11 application programming interface (API) levels currently out for Android supported devices. The API level determines which devices can operate with that particular version of Android. Each version is forwards compatible so developing for a lower API level result in more devices being able to run your application. The Android SDK is built to work alongside with Eclipse, an open source integrated development environment (IDE). The programming is completed in Java with support from HTML. Overall, the Android SDK is great development tool to produce an application, which is compatible with the ever-growing set of Android devices.

3.8.2 iOS SDK

Early in 2008, Apple released the iOS SDK to enable mobile software developers to produce applications for their platforms. This native development kit provides direct integration to the device's hardware like the accelerometer. It also allows

developers to build applications that are optimized for the device in order to take full advantage of battery and power usage efficiency. The iOS SDK is available for download and installation from Apple's webpage and it can be used with Xcode, which is the dedicated IDE for development of Apple devices. The programming language used by Apple's SDK is Objective-C, which is similar to the C++ and C languages. Additional development frameworks are provided from Apple. A notable one is the Cocoa Touch, which consists of support for touch-based interfaces such as 3D graphics, networking, and audio. All in all Apple's iOS SDK provides any developer with an excellent structure to produce a wide array of applications for the iPhone, iPad, and iPod devices.

3.8.3 PhoneGap

The alternative to developing mobile applications by the "classic" methods, like the aforementioned SDKs, is to use a framework such as PhoneGap. PhoneGap is an HTML5 framework that was created to enable mobile application developers to create products for multiple platforms with a single code project. This was achieved by providing a framework based on web technologies like HTML, CSS, and JavaScript with the APIs to interface with the native hardware to the particular targeted device. In short, PhoneGap provides a bridge between JavaScript framework and the underlying hardware to control the mobile device in order to produce a native application. PhoneGap works along with the SDKs and IDEs needed to develop for a particular platform, for example a PhoneGap SDK has been used alongside the Android SDK on the Eclipse IDE for development of Android application. This method also allows the software developer to ignore the implementation of programming languages that would normally be required to learn in order to develop for specific platforms such as Objective-C used for iOS devices. In summary, the PhoneGap API provides developers with a method to produce a single hybrid (native and JavaScript/HTML based) application, which can be ported to any common mobile device.

4 Design

Producing a device with various operational and functional characteristics within a given set of parameters comprised the design phase for this project. Serving the objectives outlined at the beginning of this document, the device is to offer the prospective user the ease of plant cultivation. To that end, many potential capabilities were pondered during group meetings. Such capabilities or "design features" serve to attain the group's objectives and to benefit the potential client. Identifying potential features that would be possible to implement with available resources represented the most creatively stimulating phase of this project. Implementing such desired features was contingent on feasibility; in terms of both skill and budget. Each group member selected a subsystem based on the selections from research, and with the intent of implementing the design features, combined the components to produce the overall system. Design is not relegated to creating and implementing features, however; optimization, safety and good engineering practices are also employed in the design process. Such guidelines

regarding safety and optimization are also provided in the objectives and requirements summary. Concessions were inevitably made; implementing one feature affected the operation of another, most often in an undesirable way that was usually related to budget or efficiency. Regarding each subsystem, the following provides detail of the design challenges the group was confronted with and the solutions incorporated therein.

4.1 General Compliance Issues

In industry some manufacturers have avoided designing wireless devices due to uncertainty of government approval and certification through the FCC. The issue of legal compliance can be straightforward. The FCC requires any device that radiates RF energy to be tested for compliance with FCC rules. The described rules are listed in the Code of Federal Regulations (CFR), Title 47. Part 15 is the section of the document that pertains with devices that emit RF energy and are to be operated without an individual license or permit. Unwanted noise or radiation can occur from motorized devices like a pump and unforeseen oscillations in a circuit design.

There are certain bands within the RF spectrum that are available for "unlicensed" operation. There are times when this topic "unlicensed" is misinterpreted. The designer of a product that is manufactured for "unlicensed" operation is not exempt from testing or the certification process. With this issue at hand, a qualified testing laboratory must test both the transmitter and receiver. Once the required approvals are received, the "end user" can operate the product mentioned without licensing. This project team has been categorized as an "end user" for Bluetooth communication devices and therefore does not need licensing or certification.

The following listings are compliance issues to be aware of:
- FCC Class B, Part 15 (Radiated and Conducted Emissions)
- Electrostatic Discharge
- Electrical Fast Transients
- Electrical Surge
- RF Conducted

Here are catastrophic failure protection concerns. If component failure occurs in the power supply, it should not exhibit any of the problems below:
- Flame
- Startling noise
- Earth ground fault
- Excessive smoke
- Fused PCB conductor
- Charred PCB

4.2 Plant

The weather had a possibility to be too cold to grow Basil; therefore the selected plant type is Mint, which can withstand the mild weather of Central Florida in the middle to late spring. It grows well in full sun, well-drained soil, with a pH between 6.2 and 6.8. It needs watered regularly, but does not appreciate too much water. It requires nitrogen fertilizer to maintain the correct pH, as well as to grow. This plant matches the criteria required for testing the PASS project.

4.3 Feedback System

The primary design issue of the sensor network is to obtain the desired response of each sensor. The device is a control system that is dependent on information collected and sent from the sensors to the microcontroller. A disturbance may represent a lack of light, water or an unacceptable temperature. The sensors collect the information that represents the disturbance, transduces the measurement to a scaled voltage and sends this to the controller. In terms of design, response from the microcontroller is only as good as the quality and accuracy of the reading from the sensor, and for this reason proper sensor calibration and connection is critical. The controller via the activation of a sub-system that serves to offset the disturbance achieves compensation that results from a disturbance. This feedback mechanism promotes system robustness and autonomy.

4.3.1 Sensor Network

Feedback Control systems activation of certain sub-systems are contingent on the value acquired from a specific sensor or in some cases a group of sensors. The distribution and interaction of the sensors, each serving a specific purpose and function are indicative to nodes in a network. Feedback ensures that the growing conditions of the plant remain optimal and stable. Additional issues involved with the design of the sensor feedback network are related to the sensitivity of the sensors, noise tolerance, resolution, and how they may be connected to the microcontroller. Some sensors have outputs that are coupled to other sensors and the conditions that relate to such dependency are programmed into the microcontroller. The optimal location of the sensors presented a design challenge as well. The following sections will expound on such issues.

4.3.1.1 pH Sensor

As previously mentioned, since most pH sensors researched are not designed to be interfaced to a microcontroller, the meter must be dismantled to find the wire carrying the output signal. The internal circuitry of a midlevel pH meter usually includes an analog to digital converter (the original signal is analog), an amplifier and a microprocessor. The microprocessor is for the display and may be discarded along with the LCD. The amplifier and the ADC may be retained or discarded, depending on the quality and price of similar parts. For example, it may be in our best interest to replace the original amplifier with a component that produces a greater gain.

The Hanna Instruments Checker pH HI98103-716435 tester was selected for this project. The meter requires a power source, which is needed for the LCD. Since the LCD has not be used, the supply power to the sensor is not needed. As previously mentioned, the current that results from the reading is actually generated from the ions as they interact with the electrodes of the pH probe. A potential difference is created when ions create a potential difference between the reference (constant potential) and the measurement electrodes. The energy is generated from the solution, and no outside power source is needed. This obviously eases power distribution requirements.

In the actual prototype, the value from the output wire of the meter would otherwise be connected to the microcontroller. The controller was to have a program that corresponds to the I/O pin that is ported to the pH meter. When an input voltage is sent to the input pin of the controller, the controller compares that input voltage level to certain conditions in the program. If the voltage level fell within a certain margin of the conditions in the program, actions are taken. The time and feasibility of this method is a concern and although it does not pose a major signal processing challenge, obtaining consistent current-pH values while configuring the microcontroller to differentiate voltage levels is expected to be problematic. Since the signal is presumably not modulated in any way, the wire transfers a relatively simple signal of constant frequency and amplitude. The following were among the most pressing issues encountered regarding the controller-pH meter configuration:

- How would the microcontroller be configured to differentiate voltage levels sent to an I/O pin?
- How would this be accomplished through the programming of the microcontroller?
- Would the voltage generated by the pH sensor exceed the voltage tolerance of the controller?

Specifying an appropriate voltage range that the controller recognizes and having the controller differentiate between different input voltages would be a relevant step to solving the pH - mV correspondence problem. Since the amount of ions in a solution is incredibly small, the quality of the signal dependent on the amplifier. A board that serves as an intermediary between the pH sensor and the microcontroller may facilitate connection issues. However, this introduces additional design and configuration issues, rendering this option to be impractical. Use of such a box may be useful if the pH device has a BNC connector rather than a bare wire. However, the use of a board that serves as an intermediary between the pH meter and the microcontroller creates additional issues regarding the processing of the voltage signal. This "solution" to a single design challenge creates several other problems. Also, the panel would add an additional block to our project that may be otherwise avoided. Consequently this option does not promote good design practice.

It is expected that the wire from the meter carries a current that is proportional to the value of the pH measured, in other words the current in the output wire is proportional to the pH value acquired from the probe. Since pH is the negative log of [H+] in a solution, setting a reference voltage level of 0 to a neutral pH of 7 needed to be established. By testing the current levels of the wire carrying the output signal in terms of a range of different pH values measured from the probe, the discernment of the electric current-pH correspondence may be attained. To that end, the meter was taken apart, a trial was then conducted, submerging the probe in buffer solutions with different pH values and using a voltmeter to obtain a voltage reading from the output wire.

This trial and error had some inherent limitations. Unfortunately, the [H+] concentration in the soil is so minute that the proportional voltage signal across the electrodes is correspondingly weak. Since the pH meter is basically a voltmeter, a large input resistance is needed to obtain a legitimate voltage reading. The impedance of the glass electrode is hundreds of Mega Ohms, making the current from the output leads of the pH meter incredibly small. Since the resulting current is on the magnitude of pico-ampers, simply connecting a voltmeter to the leads and measuring the voltage is not possible because its internal resistance is too low. A very high impedance voltmeter would be needed to obtain a reliable voltage reading because the voltage generated from the meter is so small, on the scale of millivolts. The high internal resistance of the glass electrode also necessitates the use of a high impedance operational amplifier in between the probe and the analog to digital converter. Figure 4.3.1.1-1 demonstrates the arrangement of the sensor and its circuitry.
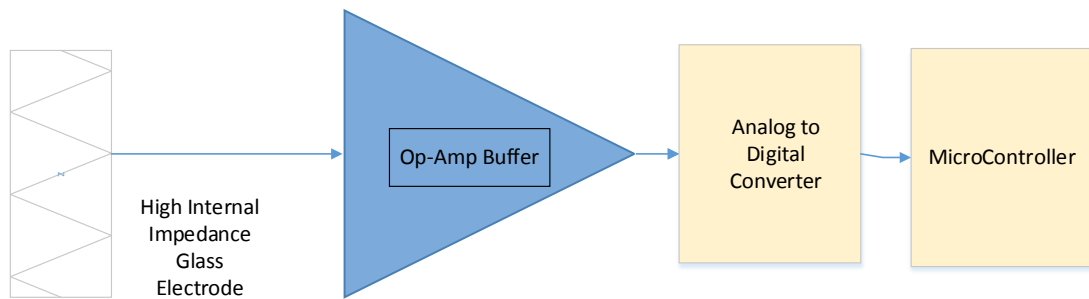

Figure 4.3.1.1-1

The Nernst Equation serves as a useful guide in correlating pH values with electrode potential difference. The Nernst Equation quantifies the relation of pH level and potential difference of the electrodes, helping the group in designing an optimal pH sensor circuit. The values generated from the equation may be plotted to obtain the correspondence between pH and electrode voltage. Such a plot would allow the group to obtain proper readings, however it is important to note that this is only an ideal approximation. There are many variations of the Nernst Equation but the equation that has been used to determine pH VS mV is:

$$ECell = E - (1.981)T(pH)$$

Since the electrode is considered a cell, the variable Ecell is actually the voltage of the glass electrode in mV. Ė is the standard cell potential and is specified for the glass probe. T is the temperature measured in Kelvin. For a certain temperature and standard cell potential, the only independent variable is the pH. Regarding the glass probe, the correspondence between voltage and pH is linear; it is common knowledge that potential difference increases .59mV per pH value. Zero volts corresponds to a pH of 7 any value below is indicative of an acidic solution; its value is negative, while a value above 7 is positive. This correspondence is ideal because the Nernst equation is only valid for dilute solutions.

PH meters on the market are capable of auto-calibration or manual-calibration. In terms of design, calibration is an important procedure because the meters performances degrade with repeated measurements. The glass electrode is continually exposed to different chemicals, including ions. Over time, these chemicals alter the structure of the semipermeable membrane; they may either permanently adhere to the glass surface or erode the glass. The meters response consequently drifts from the range of its intended output. These changes age the electrode, which is why pH meters have a limited lifetime. The response change is taken into account by calibrating the meter against solutions of known pH. A common calibration technique has used that is a two point calibration, which entails rinsing the electrode, placing it in a buffer solution of known pH and manually changing the output pH reading to match the pH buffer. The same process is completed to achieve the other point. Some sensors are capable of auto-calibration where the user calibrates the reading in the device, without resorting to the use of buffers and altering the pH reading.

Yet another challenge regarding the pH sensor was that measurement is only possible when the soil is moist, readings are not possible, or accuracy is greatly diminished, when the soil is dry. A condition was implemented in the controller to only acquire a pH reading from the sensor if a moisture condition of the soil is met from the moisture sensor. Therefore, the pH reading is coupled to the value of the moisture sensor. In addition to this, the electrode may become damaged if it is dry for an extended period of time; therefore it was necessary to keep the soil at appropriate moisture levels, with a compromise to the moisture needs of the plant.

The Rapitest pH sensor was selected. Ultimately, the group tested solutions of known pH each. The solutions had pH values of 3 to 8. By mapping the voltage to pH value, the voltage range per pH was inferred. By submerging the probe in the pH solution and measuring the voltage across the two wire leads and using the Tektronix MSO4034B oscilloscope, the voltage range was measured to be .48 mV per pH segment.

4.3.1.2 Photo Sensor

The TEPT 4400 light detector was to activate the lighting assembly when the detector fails to detect light with a range in wavelength of 750 to 950 nano-meters. Since plants are photoperiodic, the light detector was never to activate at night, so a timing function must be implemented into the controller to prevent the light from activating at night. This timing function was the primary issue regarding the design of this sensor. Some controllers are equipped with real time clocks; this feature would offer great convenience for this sensor. The location of the sensor was a design issue as well. The group did not want it to be obstructed in any way and wanted it to be placed in a location near the leaves of the plant, so the light it would detect would be similar to the plants. This location presents a design complication because the light detector is temperature sensitive and excessive heat generated from the grow light adversely affects the performance of the detector. Placing the sensor in the soil was also not an option, as the plants growth obstructs light causing the grow light to activate improperly. Most importantly, the sensor must be placed out of the way of the artificial light source. This is imperative and would create a logic error because if the light detector receives the light from the assembly, the light assembly deactivates since the sensor receives light; this cycle is repeated. The light detector was never to receive the artificial light. With these design constraints considered, the best location for the light detector is on top of the lighting fixture, on an insulating material to prevent it from getting too warm.

4.3.1.3 Soil Moisture Sensor

The Vegitronix VH400 soil moisture sensor's output is a low voltage analog signal from 0-3V depending on the moisture content of the soil; with a wait time of around 400ms for a stable output voltage. It is a 3 pin connection, containing a ground, power, and output pin. The input voltage can range from 3.3V to 20V DC, with a less than 7mA current. This product can be connected with solder or header pins. What is connected where is described in Figure 4.3.1.3-1; the output signal goes to an analog I/O on the microcontroller, while the power line needs an octocoupler to get power to the sensor only when the micro-controller or the timer wants to measure the volumetric water content.

The sensor portion of the VH400 is placed inside the pot, to measure the moisture content at the bottom of the roots. This is done to improve the growth rate of the plant and to encourage deep watering methods from the water system. The body and wires of the sensor have been contained in the electronic enclosure to prevent element exposure. There is a hole in between the electronic enclosure and the soil, which is sealed with an inductive material so the only signal that gets to the electronics is from the sensor, and this sealant prevents dirt and water getting to the electronics.
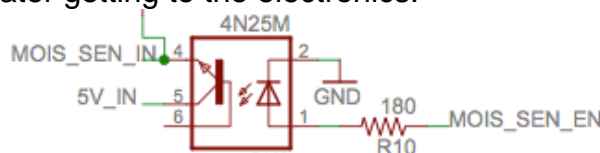
Figure 4.3.1.3-1

4.3.1.4 Temperature Sensor

The Vegitronix THERM200 requires 3.3 to 20VDC and less than 3mA on the power pin to take a measurement. The output requires 2 seconds before it has a stable measurement, with an impedance of 10Kohms. The output is be from 0-3V depending on the temperature between 40°C to 85°C with 0.5°C accuracy. To get the temperature the output is put into Equations A and B below. Figure 4.3.1.4-1 shows connections from the sensor, with the output signal going to an analog I/O on the microcontroller, while the power line needs a logic gate to get power to the sensor only when the micro-controller or the timer wants to measure the temperature, the microcontroller then puts the output voltage into equation A, to obtain the temperature in °C. This then converts to °F with equation B if needed.

Equation A: $Temperature\ in\ °C\ =\ ouput * 41.67 - 40$

Equation B: $°F = °C * \frac{9}{5} + \ 32$

The sensor measures soil temperature, but can be placed underground or on top of the ground. The PASS project places it inside the soil to be able to tell the round temperature. Therefor the sensor portion of the THERM200 will be placed on top of the ground, or close to it; the rest of the sensor is within the electronic enclosure to prevent element exposure.   There is a hole in between the electronic enclosure and the soil, which is sealed with an inductive material so the only signal that will get to the electronics is from the sensor, and this sealant prevents dirt and water getting to the electronics. The sensor notifies the watering system if it is too hot, which triggers the moisture sensor to see if there is moisture in the soil, which depending on the results will turn on the watering system to make sure the plant does not get too warm. Next time the user is connected it also notifies them if the weather conditions are inappropriate.
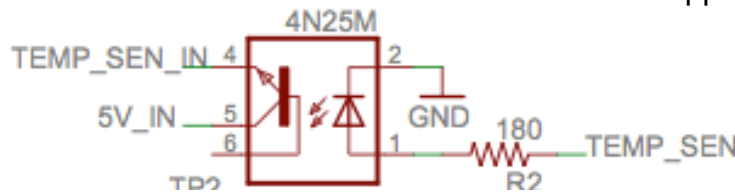

Figure 4.3.1.4-1

4.3.2 System Integration Network

This section contains the integration of the subassemblies. Cabling depicted consists of power and ground, signal-data, and system-control. The usage of shielded cabling reduces interference such as connectivity to individual sensors. The enclosure assemblies are not defined until the proto-type has been successfully tested.

4.4 Microcontroller

The microcontroller unit (MCU) is one of the core components of the PASS device, since it is the key to the autonomous behavior of the system. In addition to commanding and controlling the sensors and other peripherals of the system, the microcontroller also acts as the data collector and processor. The MCU that is used in this project is the MSP430F5342 model. Texas Instruments (TI), a well-known and reliable company in the semiconductor industry, manufactures this device. The following sections cover the overall design of the microcontroller for the PASS. This includes the MCU specifications, wireless networking, schematics, and the software development plan.

4.4.1 Specifications

A modern microcontroller comes with a plethora of technical features to explore and investigate when attempting to design a system containing one. The primary specifications to keep heed of include processing cycle time, instruction architecture, I/O pin count, power supply voltage requirements, and memory capacities. The main reason for the group's decision to choose the MSP430F5342 was due to how well the technical specifications fit the project requirements. One of the top specifications considered was the pin count since the PASS has a variety of different types of devices, sensors, and other components being attached to the microcontroller. The MSP430F5342 is a 48-pin device with 35 of those as dual purpose I/O pins, which provided plenty of flexibility for in case of any changes in peripherals used in PASS during the prototyping stage. A picture of the MSP430F5342 pin layout is provided below in Figure 4.4.1-1. A complete chart with pin numbers and descriptions is located in the appendices of this report.

Figure 4.4.1-1;
MSP430FG5342 microcontroller pin layout

Another key aspect considered was the memory capabilities. This specific MSP430 device contains 128KB of flash memory and 10KB of SRAM. This memory profile fits the estimated potential data volume that the PASS may encounter. During the prototyping stage, analysis was executed in order to verify memory requirements and updates to the design. To go along with this memory profile, the MSP430F5342 has a 16-bit reduced instruction set computer (RISC) architecture with a 125-nanosecond instruction cycle time. This instruction cycle time is referring to the time it takes for the central processing unit (CPU) to complete an instruction from fetching it out of memory to the finishing end of the arithmetic logic unit (ALU). From a power viewpoint, this microcontroller requires a supply voltage between 1.8V to 3.6V and it contains five pre-programmed power-saving modes, which assists in the overall optimization in power consumption of the PASS. There is also a monitor for the supply voltage with programmable level detection to further help in lowering power use.

Some additional features that were important to consider for this design, included the onboard communication hardware. This MSP430 model contains the Universal Serial Communications Interface (USCI), which contains hardware implementations of an enhanced universal asynchronous receive/transmit (UART), synchronous serial peripheral interface bus (SPI), and inter-integrated circuit (I^2C™). This module allows for communication between other devices located on nearby printed circuit boards (PCB). Also included in the MSP430F5342 are two 12-bit digital-to-analog converters (D/A) and a single 12-bit analog-to-digital converter, which can be used for connections with peripheral devices that require analog signals. The 12-bit ADC is a successive approximation register (SAR), which is key to understanding in order to properly

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design the software components. There are also two 16-bit timers along with a real time clock (RTC) feature, which can be used to set and track the Coordinated Universal Time (UTC). This MSP430 model has a 32-bit hardware multiplier, which enabled the design to calculate equations on the microcontroller. In general, TI's MSP430F5342 profile seems to be a great fit for the design of the PASS project due to its technical specifications.

4.4.2 Development Path

The steps to designing and prototyping the microcontroller must be carefully formulated and followed closely in order to achieve success. Texas Instruments provides development board versions of the MSP430FG4618 and MSP430-EXP430G2 LaunchPad series. These two experimental boards were first be used to update and confirm the initial prototypes of the PASS. This saved time and money during the prototyping stage since the developmental boards are flexible to connection and board changes. It also provided an interface to conduct tests with each unit prior to integrating all the components into the final prototype. The final prototype contains a custom-made printed circuit board (PCB) that has had the final layout formulated through the use of the MSP430 experimental boards. In general, the prototyping stage has had a board development that allowed for flexibility in regards to modifications of the initial design through the use of the provided developmental boards and this lead to the design of the custom PCB that was used in the PASS.

4.4.3 Communication

The PASS device in simplest terms is a sensor hub that connects an array of different peripheral systems into a single entity. This type of design is defined by the communication aspects that form the connections between the center of the system, the microcontroller, with the external devices. In short, the microcontroller is not only the commanding device, but it is the central hub where all the peripheral measurements have been joined together and bundled into a series of data packages. This data is then sent to the user interface, which is an application that sits on an external handheld commercial-off-the-shelf (COTS) device. The following sections cover the wired and wireless communication design choices for the PASS. Overall, the communication design of this project is a critical component towards success.

4.4.3.1 Wired Communication

The primary form of communication between the microcontroller and the sensor peripherals are through a series of wired connections. As mentioned briefly prior, this allows for quick data retrieval and union of the measurements from the external sensors. These connections are accomplished through using the digital and analog I/O pins that are on the microcontroller. The specific connection design can be reviewed in each of the design sections for the sensors and an overall connection schematic can be reviewed in a later subsection of the microcontroller section.

4.4.3.2 Wireless Communication

The other main form of communication that is used by the PASS is a wireless network that organizes the connection between the PASS base unit and the device that acts as the user interface. This wireless link must be able to handle secure data transmissions with the base unit from distances up to fifty feet or approximately fifteen meters. The PASS must also be able to communicate with a wide range of devices that may have different wireless networking hardware, so thus a standardized protocol is key. The issue of electromagnetic interference (EMI) must always be considered with an electrical design, especially one involving wireless communication. A device with low interference assists in containing EMI. These requirements are all included in the characteristics of Bluetooth, which is the wireless protocol used by the PASS. The following subsections go over the wireless communication design that is planned for this project.

There is a large market of Bluetooth networking hardware available for microcontroller development so it can be a difficult process tracking down the optimal one. Texas Instrument's product portfolio not only includes microcontrollers, but also a set of other semiconductor devices such as Bluetooth networking cards. The CC256x series has two products CC2560 and CC2564 and each is part of the third-generation Bluetooth core. The CC2564 is used for this application since it is developed around a dual mode architecture that allows for both Bluetooth classic and Bluetooth Low Energy (BLE). This allows for backwards compatibility as well as accommodating the devices with the latest Bluetooth protocol. The CC256x series also comes with royalty-free software Bluetooth stack from Stonestreet One that is pre-integrated into the device. In addition to this, Panasonic produces a module, PAN1326 that is integrated with the CC2564. This device provides optimized power consumption, host controlled interface module, and a built-in antenna. The initial prototype utilizes the PAN1326 with the CC2564 in order to ease implementation and integration of the wireless networking with the MSP430 microcontroller.

The CC2564 Bluetooth module must be connected to the microcontroller to establish the wireless link to the user interface. This is achieved by using the universal asynchronous receive/transmit (UART) module, through the H4 protocol that is a 4-wire interface. The connections include the transmitted data, received data, clear-to-send, and request-to-send lines. Figure 4.4.3.2-1 below shows the connection scheme between the microcontroller and the CC2564 interface.
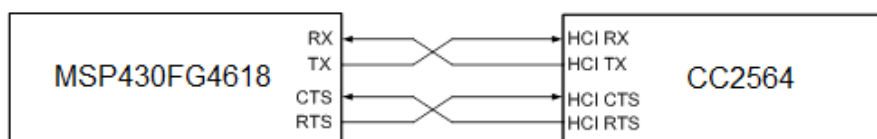

Figure 4.4.3.2.-1;
UART connection profile for the CC2564 module

Changing the settings within the associated software component can control the 4-wire UART. The baud rate can be changed to a maximum of 4Mbps after the initial startup through a command. The setting for parity is by default not included, but it can be changed through a similar process as modifying the baud rate. This H4 protocol handles transition between active mode and sleep mode through the CTS and RTS to support the power management. The VDD_IN and VDD_IO pins supply the power source for this device. The PAN1326-CC2564 also contains a power-management module that optimizes the power draw. The CC2564 requires a slow clock and fast clock. The slow clock should be connected to the SLOW_CLK pin and it can be the crystal-oscillator from the host or an external oscillator at 32.768 kHz. The fast clock input can be provided from an external crystal oscillator with a frequency of 26 MHz and connected via the XTALM and XTALP pins on the CC2564. This summarizes the main connections required for the CC2564 Bluetooth module with the microcontroller.

4.4.4 Schematics and Connections

This section, in Figure 4.4.4-1 is the MCU component integration with emphasis on the sensors, Bluetooth, and the power configuration. The remaining components are the switches, USB port, battery, LCD and LEDs which have less significance with the initial design. The power circuitry was modeled after the MSP430 Eperimenter's board and has not been altered. The figure shown is referenced again in the Appendix section in order to show clarity. Table 4.4.4 shows the Bill of Materials for the associated drawing of the PCB.
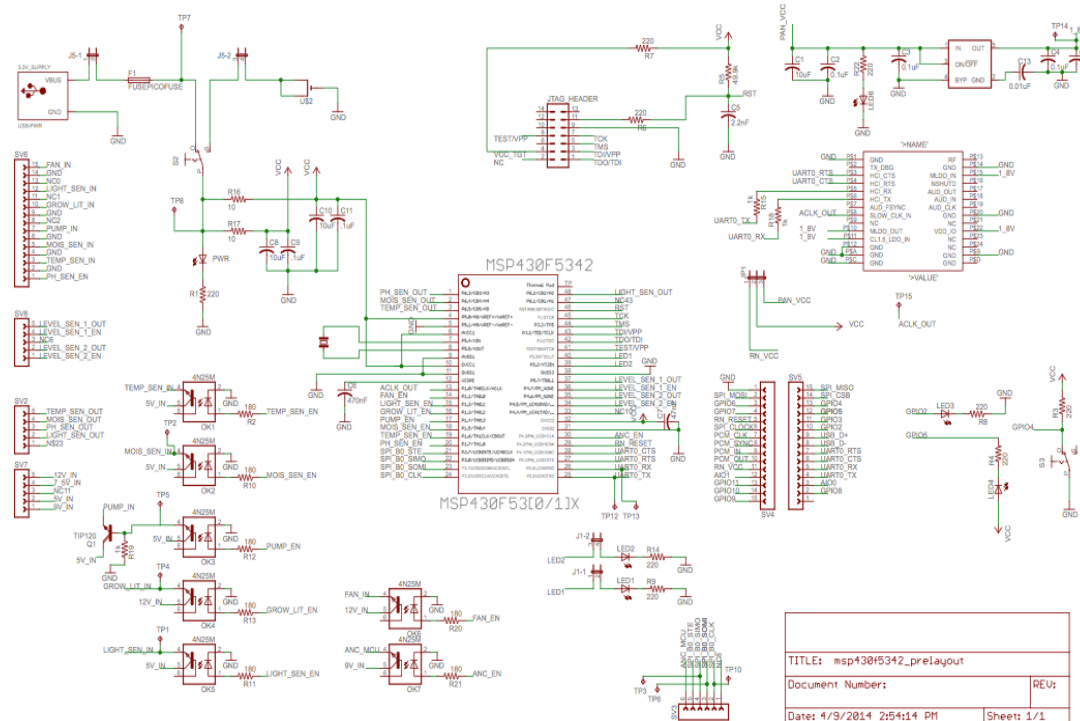

Figure 4.4.4-1;
Overall MCU connections

Table 4.4.4-1; PCB BOM					
Item#	Req.Qty	Value	Package	Manuf. P/N	Price
1	2	LP2985-XXADBV	SOT23-5	595-LP2985-18DBVR	0.68
2	3	USB-PWR	UX60-MB-5S8		1.25
3	2	10uF	C0805	0805ZD106KAT2A	0.03
4	3	0.1uF	C0805	0805C104J8RACTU	0.063
5	1	2.2nF	C0805	MC0805B222J500CT	0.031
6	1	470nF	C0805	0805YC474JAT2A	
7	1	47nF	C0805	08055F473KAT2A	0.062
8	2	10uF	C0805K	08056D106KAT2A	0.041
9	2	.1uF	C0805K	08055C105MAT2A	0.448
10	1	0.01uF	C0805	08052C103KAT2A	0.036
11	1	FUSEPICOFUSE	PICOFUSE	0251.750PAT1L	0.85
12	2		JP2Q		
13	1		JP2		
14	3		MA07-2		2.99
15	12		SML0805	SML-LX0805SUGC-TR	0.3
16	1	F53[0/1]X---RGZ48	RGZ48		**Rcvd**
17	7	4N25M	DIL06	4N25-M	**Rcvd**
18	1	PAN1326"PAN"	LGA		**Rcvd**
19	1	TIP120	TO220AH		**Rcvd**
20	2	32kHz	TC26H	ABS07-32.768 KHZT	1.71
21	9	220	R0805	CR0805-FX-2200GLF	0.008
22	7	180	R0805	CRCW0805180RFKEA	0.004
23	1	49.9k	R0805	CRCW080549K9FKEA	0.012
24	3	1k	R0805	CRCW08051K00FKTA	0.011
25	2	10	R0805	CR0805-JW-100ELF	0.012
26	2		EG1218	EG1218	0.287
27	6		FE05-1		0.4
28	3		FE06		0.5
29	6		FE15		0.95
30	13	TPTP16R	TP16R	1502-2	0.443
31	1		CR1220-SMD	3000	0.32
32	1				
	103	**Total**			

4.4.5 Software

The design considered for this project warrants a microcontroller with a sufficient sized software component. It is one of the key features to provide the smart and autonomous behavior of the PASS. Some of the design issues need to be

addressed by the software component include sensor polling, Bluetooth communication with the user interface, and overall data management, the controlled mode. The autonomous mode is the free running behavior that takes care of the user's plant, whereas the controller mode is when the user is sending commands to the system via the user interface. Therefore, the software architecture follows a cooperative multitasking design, which provides a simple control loop with a series of interrupts that determine the next sub-process to run. The main advantage to this design is the ease of adding new tasks since they can be appended to the main control loop. Testing and close analysis is required for cooperative multitasking to ensure a minimal amount of process starvation. The following sections cover the aspects of the microcontroller software by first covering the autonomous behavior followed by the application-controlled behavior.
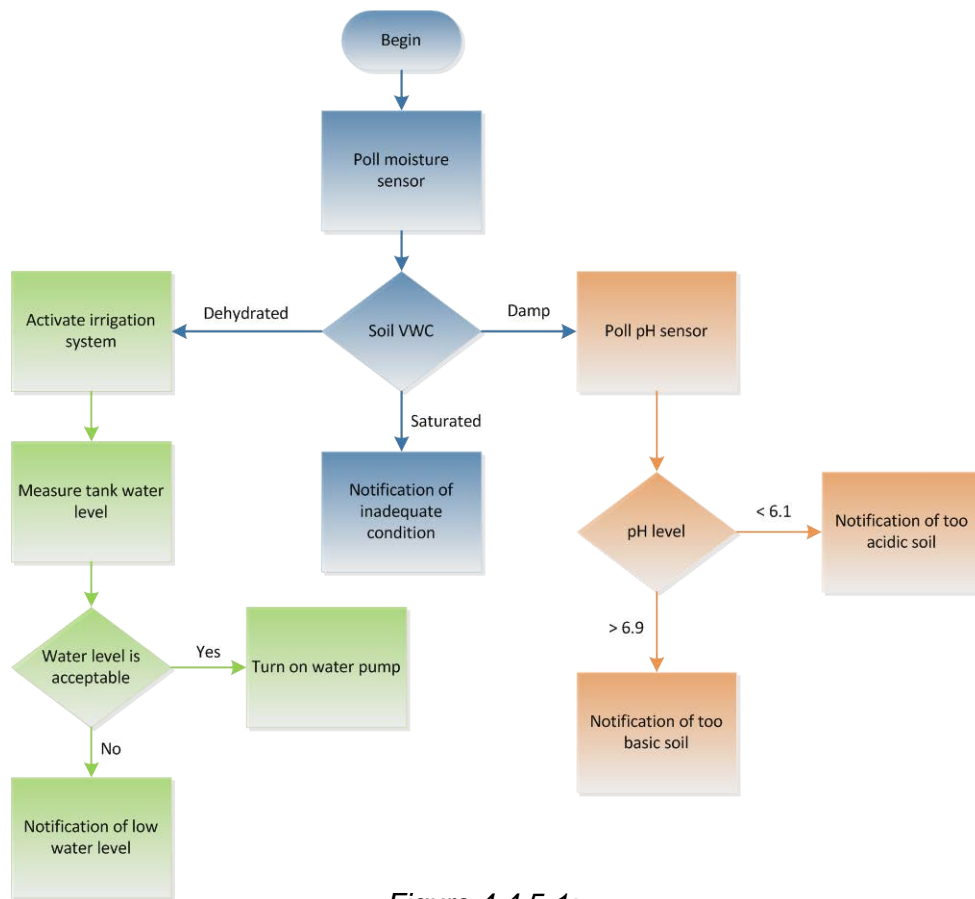
Figure 4.4.5-1;
Moisture, Water Level, and pH sensor decision flow chart

One of the main software activities is the polling of the external sensors and recording their measured data. The autonomous behavior is largely affected by the measurements that are collected from the sensors. Some of the reactions of the system depend on multiple conditions, which are formulated from the values measured from the sensors. Figure 4.4.5-1 shown below summarizes the

decision path when the system proceeds to gather information from the moisture and pH sensor.

Figure 4.4.5-1 divides the moisture, water tank level, and the pH sensor as blue, green, and orange sections, respectively. The moisture sensor is always checked first on a periodic basis depending on the plant and environment. This is due to the dependency that is formed from the fact that the pH sensor must have moist soil to acquire an accurate measurement. If the soil is damp, then the pH sensor is eligible to be measured and it is activated if it has not been polled within a time period, which is defined on the plant sensitivity. If the pH sensor reading is outside the recommended limits, then the system notifies the user via the user interface application. If the moisture sensor returns a result meaning that the plant is dehydrated, then the water pump is activated so long as the water tank has enough water. If the water tank becomes low, the system notifies the user via a request for water. The water is also be tracked by time in order to tell the user when to empty the tank and provide fresh water for the plant. In general, the water tank, soil moisture, and pH sensor have dependencies between their statuses and operation.
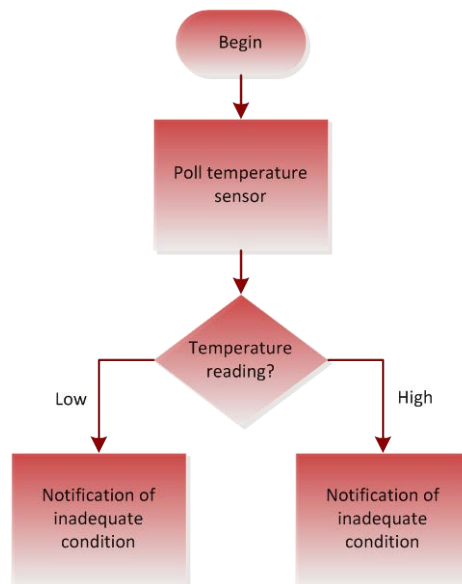
Figure 4.4.5-2;
Temperature sensor decision flow chart

The temperature sensor located on the perimeter of the PASS enclosure is polled similar to the moisture sensor. The conditions associated with the flow diagram of the temperature sensor are shown in Figure 4.4.5-2. Temperature measurements are taken at a periodic cycle and if the readings are outside the accepted values for the particular plant, then the system notifies the user of the problem. This feature is implemented in order to provide a feedback system that reminds the individuals who might want to leave their plant outside, but don't want to leave their plant out during a cold night. The temperature feedback

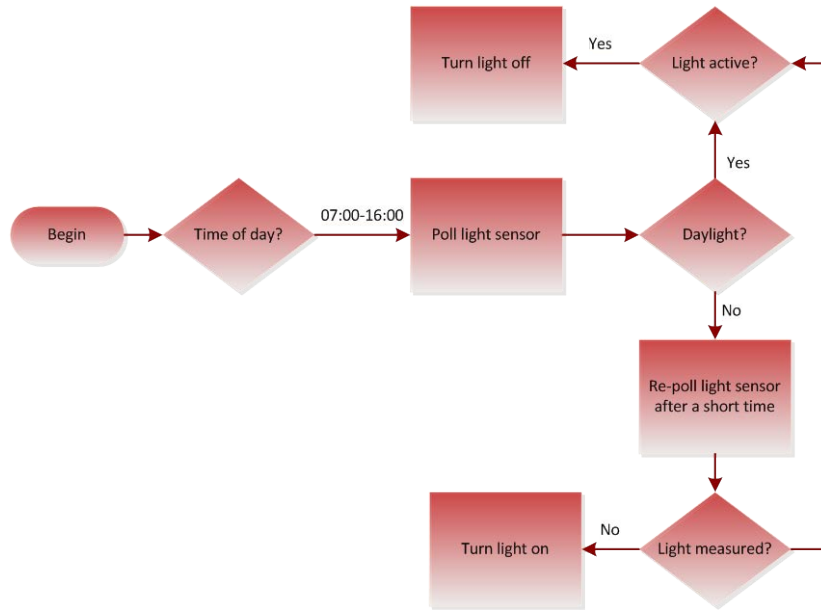process is adjusted for the particular plant and environment, outside or inside use, of the PASS.

Figure 4.4.5-3;
Light sensor decision flow chart

The other main sensor that needs to be directly controlled by the software module of the PASS is the light sensor as shown in Figure 4.4.5-3. This sensor is used to determine if the plant needs light and it activates the grow light if certain conditions are met. By default, the light sensor is only be polled during times of daylight, which is adjusted accordingly for the seasons and time changes through time calibration with the user interface module. The light sensor is shut off if a light source is sensed or if the time is calculated to be within the evening hours. In short, the light sensor needs to be tightly coupled with the RTC and the other microcontroller timers in order to provide a balanced amount of light to the plant.

The other period in which the sensors are activated shall be if the user sends commands via the user interface. The PASS microcontroller has to decode the command received via the wireless connection and then form schedule requested task. The sensors activate similarly to how they would in the autonomous state of the PASS, but the system notifies the user with a warning if it is not recommended to activate certain peripherals. An example would be if the user requests a pH reading and the soil happens to be too dry or wet for an accurate measurement, then the microcontroller sends a warning notification via the user interface.

As briefly mentioned prior, another main process for the software to handle is the communication via Bluetooth with the user interface. A form of handshaking must occur during connection startup and this is an acknowledgement step that includes sending the clock time of the user interface device to the

microcontroller. This provides an offset in time so to assist in establishing a clear presentation and accurate form of the time-dependent data to the user. After the acknowledgment process, the microcontroller sends reserved data to update the user of a brief status history of the PASS. While the microcontroller is in an active connection with the user interface device, a form of interrupts is initially sent in order to set the microcontroller to command mode. During this mode, the system must be prepared to receive commands from the user such as the sensor measurement requests that were discussed in the previous paragraphs. There is a component of the wireless management that will put the Bluetooth module into a sleep mode and return the system to the autonomous mode. This increases power efficiency and optimization. An LED is used to notify the user of the Bluetooth connection status. Another LED flashes when there is a system notification for the user. This will help keep the user informed even while there isn't a wireless connection between the user interface and the PASS. In short, managing the Bluetooth communication is the key in maintaining a cognizant user of the PASS.

The final main process of the software component of the microcontroller for the PASS is data management. The microcontroller has to collect data from the peripheral sensors and send it to the external user interface for display. As mentioned prior, the data is sent through the Bluetooth connection established with the user interface. A form of logic must be considered for when the system does not have an established wireless connection. During this time, the software stores data until a new connection is made with the user interface. There is a limited amount of memory space, which is reserved for holding onto data. This historical data is stored in a queue structure so when space runs low, the system removes the older data to make additional memory space. Overall, the data management of the PASS is flexible and organized since it is a critical component of the notification system.

The software development process for the microcontroller entails careful implementation, testing, and analysis in order to ensure an efficient operation for the PASS device. TI provides the code composer software, which is an interactive development environment (IDE) to be used alongside their microcontrollers. This program runs on top of the Eclipse environment, which provides key features such as debugging, memory browsers, and other general tools that assist in software development. Overall, the software component of the microcontroller is a key asset to producing as close to a fully autonomous system as possible, which is sought for the PASS.
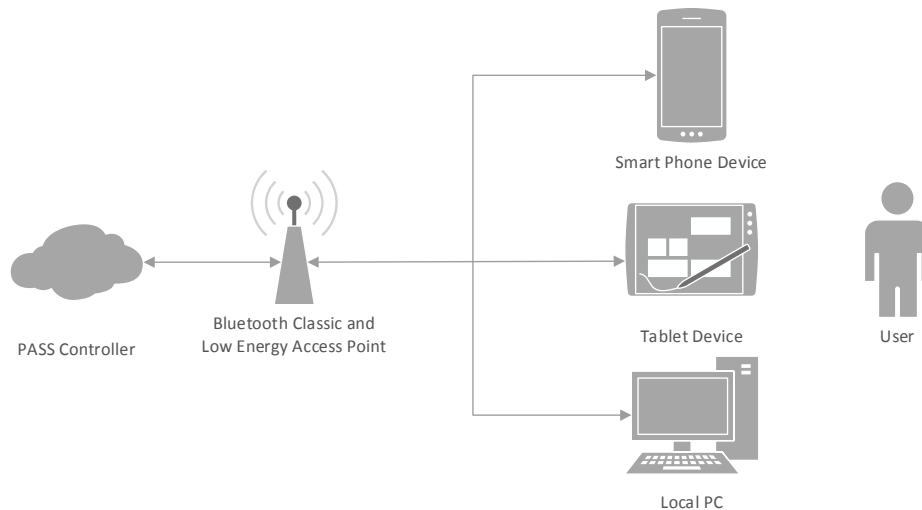
4.5 User Interface

As mentioned earlier in this report, there are many options when it comes to developing a GUI for a system such as PASS. In order to simplify hardware integration and turn over time, the decision was made to develop an application that would be used with a commercial off the shelf (COTS) mobile device such as a phone or tablet. This choice leads to a few different options for development

techniques such as the common software development kits (SDK) provided by Google and Apple for Android and iOS integration, respectively. These two development environments would be excellent if the project was targeting a single platform, however this project has a requirement to have compatibility with a majority of mobile devices. This priority points to using a development strategy that targets multiple platforms with a single code base, which is where PhoneGap comes in to play. PhoneGap provides a single framework that enables creation of a single source code project to be compiled for multiple mobile platforms such as iPhone, iPad, Android, Windows phone, and more. The other main reason PhoneGap was chosen over "classic" methods of mobile application development techniques is that there is a large amount of support material provided through forums and manuals available for assistance in overall development. The following sections will cover the software for the user interface of the PASS.

4.5.1 System Overview

After careful consideration of the core requirements, a client-server design is an excellent fit for the user interface software of this project. At its core, this architecture consists of a client that requests services from a server that is likely to be external to the hardware where the client software resides.

Figure 4.5.1-1;
Overview of User Interface

The diagram shown in Figure 4.5.1-1 reflects the overall connection scheme and interaction between the user and the PASS. As briefly mentioned before, the user interface software is designed for use with a COTS device such as a smart phone, tablet, or a local personal computer. These devices are configured to make a connection between a dual mode Bluetooth Classic and Bluetooth Low Energy device, which is directly linked to the PASS. This connection allows for

fresh data to be transferred to a visual display for the user to explore along with a remote controller to send commands to the PASS device.

4.5.2 Management and Organization

The overall success of a software project can be traced back to the management style that was implemented. This can be broken down into a few core areas including software life cycle, configuration management, and coding standards. An overview of each of these ideas along with explanations of the decisions made with regards to these topics will be discussed in the following subsections.

The software life cycle refers to the development pattern that software developers follow for a specific coding project. This covers the order and length of phases that can be broken down into tasks such as software design, requirements review, prototyping, testing, and release. This project requires a short-term development cycle with a flexible schedule to accommodate the potential of changes in the hardware design that could have an effect on the software design. These characteristics fit well for an agile development style, which is based on the iterative and incremental strategy, but it was created for software development that is unable to support long-term planning and development cycles. This process strongly supports teamwork within programming teams and it is common for pairs of developers to work together on certain code pieces. This fits this project well since there were two individuals working on the software and they can collaborate between themselves closely on a frequent occurrence. Another reason that agile development fits this project is the fact that it is flexible with changes in requirements by valuing response to changes over following plans. In summary, this project follows an agile development style that composes of simultaneous work in requirements analysis/review, prototyping, and testing in order to promote quick development.

A configuration management system is crucial to maintaining software assets and keeping track of the overall condition of the project. The PASS project utilizes the GitHub server in order to store and version developed code and relevant documents. This assists in the general management associated with software storage and provide a secure location that counters any problems that could occur on someone's local computer. A series of comparison and merging tools such as Beyond Compare and WinMerge is used in conjunction with GitHub to guarantee a safe practice of code merging and updating during the development process.

The coding standards for this project is followed and maintained by the software developers. These standards consist of the general structure of the code and the practices associated with software development. One of these rules is that every project file contains a comment header that consists of the project name, file name, file version, and a modification history block that is a list of entries that have the date modified, author that contributed the changes and a concise description of the code changes. This header assists in general code

maintenance through enabling a tracking history. In addition to this, the coding structure follows a mixed case "camel" convention with two-space tabs. All ambiguous code contains comments explaining the purpose of those lines and each function has a signature comment containing the function's parameters, return type, and brief explanation of execution.

4.5.3 Code Implementation

As mentioned briefly earlier, the software development for this application was completed through the PhoneGap SDK along with the associated SDKs for each targeted platform. The environment of PhoneGap is a web application, which consists of Javascript, HyperText Markup Language (HTML), and Cascading Style Sheets (CSS). The HTML code was used as the structure for the graphical user interface (GUI), such as defining the GUI components like their location, size and more. The CSS component was used alongside the HTML pieces to provide style to the GUI, for example it does the setup for a button's color and font. The Javascript code defines the programming behavior for the GUI components. It basically describes the actions for the GUI components and it is the "behind-the-scenes" worker for the GUI-driven application. Javascript is a multi-paradigm language that supports object-oriented, imperative, and functional programming. This project incorporates Javascript, HTML, and CSS coding languages in order to produce an application compatible with an array of different platforms.

4.5.4 Software Requirements

Requirements specification is a critical component to consider during the design of a software product and this is no different for the software-related items of PASS. In order to further simplify the design and implementation of this software program, the requirements are broken up into two main types, functional and nonfunctional. These terms refer to the required behavior for certain activities and the quality characteristics that the solution must possess, respectively. These requirements can be further subdivided into categories such as essential, desirable, and optional to provide a better description for designing and planning purposes. This can allow for proper choices in implementation orders by understanding what is really needed and what can be saved for later versions. This set of requirements is flexible to change during the design and implementation and process of software development phase. Table 4.5.4-1 contains the set of requirements for the user interface application used in the PASS is shown on the following page.

No.	Description	Priority
	Table 4.5.4-1	
	Software Requirements Table	
01	The system must be compatible with the major mobile devices out in the current market.	Essential
02	The system reports and notify any errors or faults within the user interface.	Essential
03	The system must notify the user of any problems with the PASS.	Essential
04	The system allows the user to choose notification settings.	Desirable
05	The system must be able to display a variety of statistics and information about the PASS.	Essential
06	The system must be able to display a variety of statistics and information about the user's plant.	Essential
07	The user interface must be able to store a history of data about the entire system.	Essential
08	The system must be able to communicate with the PASS through wireless means.	Desirable
09	Everything the system displays must be clear and understandable.	Essential
10	The information displayed is organized through user settings for display options.	Desirable
11	The system is responsive to user requests and actions.	Desirable
12	The system allows the user to back up any information collected from the PASS.	Optional
13	The system leaves a small memory footprint on the user's mobile device.	Essential
14	The system allows the user to control the PASS via their mobile device.	Essential
15	The system is separate from the mobile device's operating system kernel.	Desirable
16	The system is able to communicate to multiple different PASS base stations.	Desirable
17	The system is organized in order to be a simple-to-use application with little to no training.	Desirable
18	The system contains a brief tutorial/instructional dialog during initial use.	Desirable
19	The system is able to contain a database with information on at least 10 different plants.	Desirable
20	The system must allow for multiple users	Optional

4.5.5 Software Components

The user interface application can be broken down into software modules. This allows for full exploitation of object oriented programming through utilizing the core principles of such as polymorphism and inheritance. This division allows for simultaneous development of multiple pieces of code due to the independence between modules. It also simplifies the integration and testing of the software since each module can be analyzed independently and brought together in any sequence. The software modules of the user interface consist of graphical user interface, wireless services, data message, and memory management. The graphical user interface (GUI) is dealing with the layout and style of the application. The flow chart diagram below shows a higher-level view of the paths that is in place for the GUI of the application.
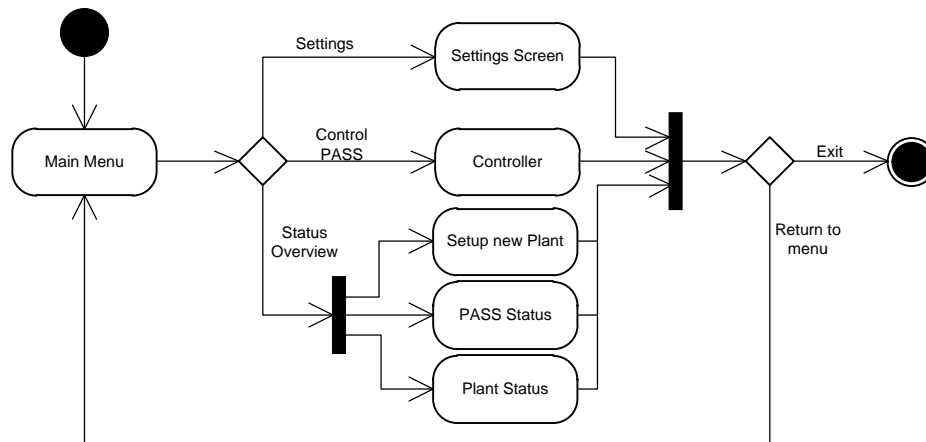
Figure 4.5.5-1;
User Interface Menu Flow Chart

The PASS user interface is a page-based application and that is easily seen from Figure 4.5.5-1 shown above. The application contains five main pages that are connected by a main menu, which is shown at start up. The user is able to traverse through the application by buttons on the menus as well as the back and/or home buttons that are built into the physical device that is displaying the user interface. During first use of the application, the user is provided with options to setup wireless connections with the PASS microcontroller and questions about the plant is asked in order to create a profile that is used to assist the PASS in its autonomous behavior. The controller menu of the GUI provides options to send commands to the PASS, such as turning on the grow light or the water pump. The control interface also supports sensor readings in order to show the current status of the entire system. These readings not only include the sensors associated with the plant, but also some of the sensors used to maintain the subsystems of PASS, such as the temperature of the electronics. All of these readings can be easily customized in order to display only the information that is interested by the user. The settings menu provides the user with options for the application, such as Bluetooth connection, notification, and

display layout settings. Some setting options include automatic wireless connection between the PASS and the user's device.

Another key software module is the wireless services, which consists of all the connection protocols and methods between the PASS and the user's Bluetooth enabled device. This component maintains and follows the settings defined by the user and Bluetooth protocol. It also has functions that convert the data format that is being sent over the wireless link. This includes translating the information received from the microcontroller into the data message format used by the application. The other translation is converting the data prior to it being sent over Bluetooth into the format used by the microcontroller. The data format for the microcontroller is covered in the microcontroller section of this report. The conversion between data formats is achieved by parsing the bytes sent via Bluetooth into structures that are defined inside the Data Message class of the user interface.

The data message software component contains the definition of the structure and format of the data being stored on the user interface application. As mentioned earlier, this module is used alongside the wireless services in order to convert the data being received / transmitted from / to the PASS microcontroller. The information contained in this module is also be used as the main source of data for the displays of the graphical user interface. The memory stored on the user's device is in a similar format to the defined structure of the data message component. Memory management module for the application is used to store and retrieve plant information in order to maintain a short history of the plant status data. This component is also attempt to flush out old information in order to maintain a low usage of physical memory. Overall, the data message component houses the information for the PASS, user's plant, and commands to/from the microcontroller.

All of the aforementioned components are located in the unified modeling language (UML) class diagram shown below in Figure 4.5.5-2. This class structure defines the overall structure for the application and shows the relationships and interactions between each software module. The GUI interfaces with these classes in order to display relevant information to the user, for instance the controller menu sends commands to the microcontroller on the PASS by creating command data messages, translating them via the data translator, and sending the information through the wireless service. The data translator and data calculations are singleton classes that manipulate the data stored in one of the classes that has implemented the Data Message interface.
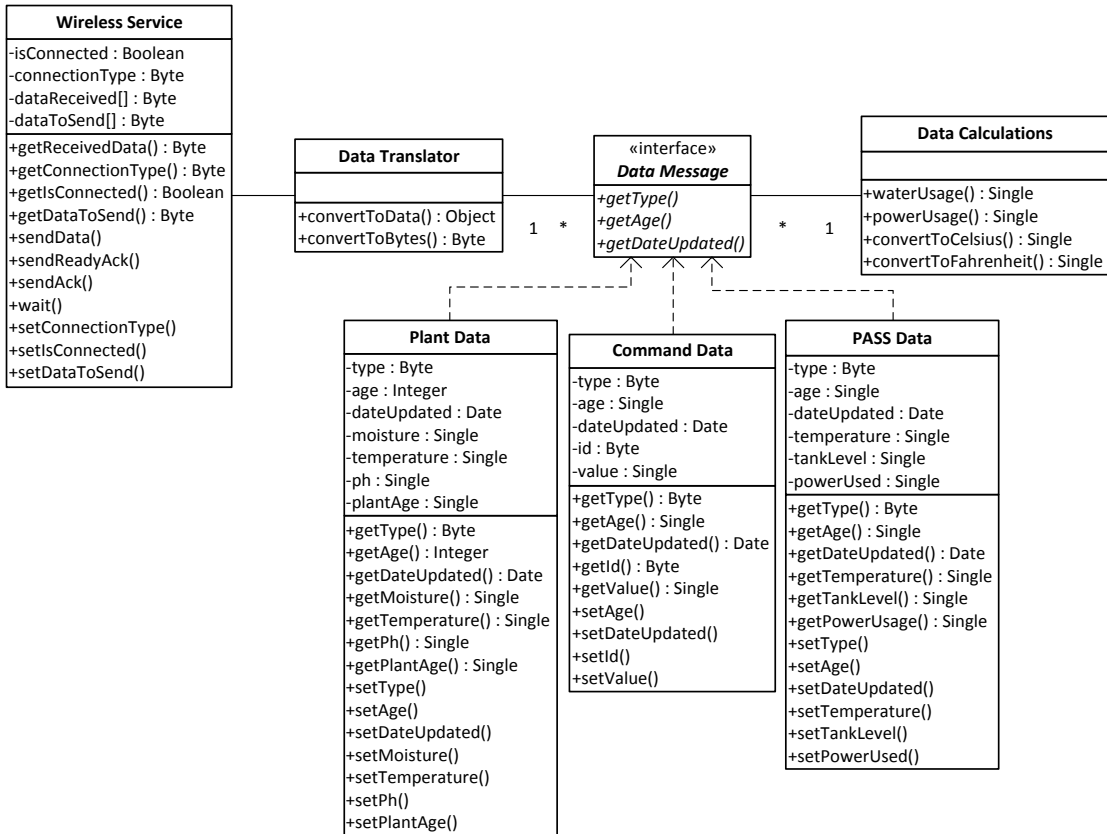
Figure 4.5.5-2;
Class diagram of User Interface Application

The class diagram shown above summarizes the design of the PASS application software. It is followed closely during the code implementation phase and if needed, it shall be updated accordingly in order to maintain accurate documentation of the application code.

4.6 Enclosure Design

When designing the enclosure of the prototype, we must be cognizant of the subsystems that define the device, which include the irrigation system, container for the plant, lighting assembly, and the electronics. The enclosure must conform to the shape and size of these systems because it is required to be portable and to separate the electronics systems from the other systems. It houses the microcontroller and power distribution system, which is located separately. The reservoir is located beneath the container that holds the plant. The material of the enclosure must be water resistant and insulate the sensitive electronics of the device from humidity, as moisture could damage them. Despite this, there still is a great deal of freedom in designing the enclosure. The final design is depicted in Figure 4.6-1 below.
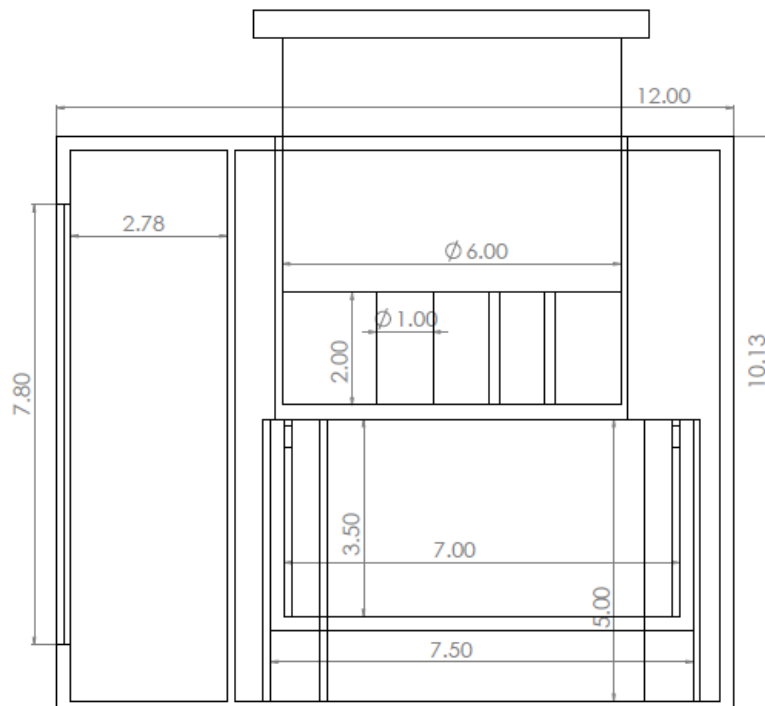
Figure 4.6-1; PASS Enclosure Assembly
This illustration was drawn using SolidWorks educational software

As previously mentioned, the optimal water temperature for plants in terms of photosynthesis is 25°C. A margin +/- 6°C is accepted, anything beyond is not. The temperature and humidity levels in the electronics compartment are to be maintained at the lowest humidity value and temperature value that any one of the components may tolerate. In other words, if the Bluetooth module has the lowest humidity and temperature acceptance range (~80% relative humidity, ~15°C to ~85°C temperature), the temperature and humidity values in that compartment must be maintained at those values. Acrylic was selected for the design of the enclosure material for its low cost, low weight and relatively high heat capacity. Other materials offered better specifications but they were more expensive.

Activation of the fan could be periodic or it could activate when the temperature exceeds a certain threshold or both. A thermometer that sends the temperature to the controller would need to be placed in the compartment, the controller would then activate the fan when it recognizes a high temperature. Periodic activation of the fan would require a timer. This method has a limitation in that the fan may be activated at certain times that are not necessary resulting in a waste of power, producing an undesirable design feature. During prototyping, the group intends to experiment with the possibility of placing a fan and thermometer in the electronics enclosure and configuring them to the controller to activate the fan at temperatures exceeding 50°C. The fan permanently switched on but would actually only receive power from the controller to activate if the temperature

sensor detects a level that is too warm. The fan selected for the prototype is the StarTech FAN6X1TX3.

The effects of humidity generated not only from ambient conditions the device is exposed to but also the water from the reservoir of the irrigation system, may damage the electronics. The area that houses the microcontroller and power system must be isolated from the reservoir. Because of the compact structure of our device and the proximity of the reservoir and the electronics, this requirement imposes a number of challenges on our design. We considered many options regarding sealing the electronics from the humidity and perhaps utilizing a fan to mitigate the effects of the humidity. Every cubic inch of the enclosure space serves a purpose and space is very limited. The primary issue we have is that the electronics area and the reservoir must be accessed periodically; sealing these areas with a sealant such as caulk is not an option as access would be problematic. To promote satisfactory design practices, we decided to separate these devices from each other inside isolated compartments within enclosure, as far away from each other as possible. Fabricating such an enclosure with isolated sub compartments is very costly; the group is currently considering completing the actual fabrication. The planting container that holds the plant is a separate structure from the enclosure on the top and bottom. The bottom enclosure area is to contain the reservoir and the electronics area.

The only design issue with this option is that after about one month average, the silica gel becomes saturated with water and must be heated to remove its accumulated moisture. This is accomplished by "recharging" the silica crystals, which entails plugging the device into an electrical outlet for 2 to 4 hours and allowing the thermal energy of the electrons in the current to release the water from the silica gel, thereby vaporizing the water. The silica gel associated with the Eva-Dry is doped with indicator molecules that display a spectrum of color with respect to the amount of moisture the crystal absorbs. So the moisture the crystals hold is indicated by their color; a certain color indicates that the crystals must be recharged. Removing the device from the enclosure somewhat compromises the objective of near-complete autonomy of this project, however, this procedure is only required on a monthly basis and not weekly. This step may be completed when the pH sensor is to be manually cleaned and recalibrated. An electrical dehumidifier, with a condenser, which could be activated from the microcontroller via the hygrometer sensor, would not have to be removed monthly and would offer a fully "autonomous" solution. The trade-off with this option is its large size and large price. Some of the objectives for this project are autonomy, expense and size. And some design goals must be compromised to meet other design objectives; it is up to the design team to make such decisions.

4.6.1 Lighting Assembly

The growing volume of the environment is going to be small; therefore a power consuming ballast is used for this application. A small domestic fixture was chosen, either a screw mount socket or bayonet type. These fixtures are

relatively inexpensive (~$15) and readily available at a local hardware store. However it is critical that the fixture has the proper voltage, current and power (wattage) specifications. Since our likely selection includes the low power LED bulb, these factors should not be an issue, in fact; most Edison Screw Mount Fixtures have maximum ratings for 120 Volts (E26) and 660 Watts. The size of the fixture is small and its placement is both a function of the enclosure shape and the distance it may be placed from the plant. Its distance is based on the amount of heat and light the bulb generates (greater heat, further away from plant; less light output, closer). For our design and prototype the E26 was picked as the mount for its versatility with different bulb types, power and voltage characteristics.

The power that the bulb receives is a major factor in bulb selection. Most bulbs require alternating current and this requires that an inverter be placed between the bulb and the power station. LEDs however may only be supplied with DC current. This created a design complication and the group was very surprised to learn that common consumer LEDs are equipped with hidden, elaborate circuitry to rectify the AC current, converting the current to DC. Unfortunately, most LEDs are equipped with this circuitry which necessitates the use of a heavy, expensive inverter we would not normally need for this bulb type. Of course, LEDs without this expensive circuitry are common but specialty grow lights that generate the necessary spectrum of light, without this circuitry were not available.

The LED grow light demands very little power, only 3 watts. Since the circuitry built into the LED bulb converts the alternating current to direct current, an inverter must be used. The E26 socket is designed for AC but it may accept DC. The compatibility of the E26 socket with DC was questioned and its consistent performance with DC has not been conclusively proven. It was decided that this would be a questionable design choice in terms of electrical safety. The group considered dismantling the LED to remove the rectifying circuitry. Unlike the Compact Fluorescent, LEDs do not contain mercury but the disassembly seems cumbersome. Regardless, the socket is designed for AC. These options may be considered after the initial prototype is created, if safety is ensured.

To promote proper design practices the group decided to employ an inverter to convert the DC from the power source to AC for the lighting fixture. The Samlex Pure Sine Wave Inverter was selected for this purpose. The inverter offers a NEMA 5-15R receptacle to plug the wires that are connected to the E26 leads. The inverter is built with overload protection and the minimum idle time is has a power consumption of less than .85mA. The only drawback to incorporating the inverter into the design is that the inverter is about 2 inches thick, 6 inches wide and 8 inches tall, so its presence increases the size of the enclosure. The E26 has three wire leads connected to it; the hot lead, the neutral lead and the ground lead.

Design and construction of the lighting apparatus that holds the bulb is important with respect to the appearance of our prototype as well as power regulation and efficiency of the device. Placing the fixture in the planting environment is a design choice that is dependent on several design constraints. One such constraint is the distance the fixture may be placed from the plant. Fixture should not be too close to the plant to avoid damage to the plant. The bulb must also be shielded from rain and excessive amounts of dust. The lighting mount may be fastened to a rail on the enclosure or part of the greenhouse. A gooseneck lamp with a bendable shaft is under consideration. This choice is favored because it allows us to modify the direction of light. The gooseneck fixture is primarily compatible with the Edison (E26) screw mount, not the bayonet mount. The source energizing the lighting assembly is addressed in the power system section.

The placement of the grow light in terms of both the enclosure and the plant was critical design guideline regarding the lighting assembly. A gooseneck lamp with a flexible shaft was purchased from Target for about $7. The lamp was taken apart and every component was discarded except for the flexible shaft and clip. All four wires (two from the E26 fixture, two from the sensor) were fed through the shaft from the light and sensor. The E26 mount was fastened to the shaft by connecting it to a PVC coupler. Plumbers Putty was used to fasten the PVC reducer to the shaft and E26 fixture. A small hole was drilled through the PVC reducer; the photo-transistor was fed through the hole and placed on the PVC reducer. The four wires that are fed through the shaft are then connected to the MCU. The wires were cut, stripped, tinned and soldered to each other; heat shrink was also applied over the connections to insulate the wires. The bottom of the shaft is connected to a clipped on to a flat piece of acrylic that extended from the enclosure. This assembly was painted black. Fastened to this pole, the bulb and mount are compact and have a combined weight of 10oz. The complete unit weighs about 25lbs. The placement was contingent on the amount of heat generated by the grow light and the amount of light it generated per volume. In terms of design aesthetics, the group did not want the pole on which the grow light is fastened placed too high above the enclosure, which would create an ill-proportioned appearance. To meet this design characteristic, the selected bulb generated minimal heat, rendering the acceptability of its close proximity to the plant. Also, this ensures that the plant will obtain adequate light. Both the light and fixture are waterproof for safety and durability, promoting satisfactory design standards. The LED bulb which was compatible with AC/DC and was purchased from GoldenGadgets.com for $29 and implemented into the project. It was selected based on its wide spectrum, minimal heat generation and low power consumption.

4.7 Water System

The water system includes the designs for the water tank irrigation system, water pump, and water level sensor. The system feeds water to the plant, as well as be able to collect water from rain collection; the user is able to fill up the water tank as well.

4.7.1 Water Tank

The water tank's design was finalized after testing. It home made with a durable acrylic that is able to withstand the measured holes for irrigation tubes, power chords for the pump, and the water sensor power and feedback leads. It also has an opening with a mesh filter on top to allow either the user or rain to fill up the tank.

The water tank is placed under the pot and next to the electrical enclosure. This is because the weight of the water and the pump needs to be on the bottom, not crushing the electronics when full.

4.7.2 Irrigation System

The irrigation system was hand built to save money and water. It is similar to a soaker hose and drip irrigation system, with a hose size that matches the pumps output requirements, which is 7/16th inch. The hose only has holes where the plant is to conserve water, but it does not have all of the parts required for a drip irrigation system. To prevent leakage at the end of the tubing into the plant a 5/8th inch screw was inserted into the end of the tubing, then glued down to prevent leakage. The pot and sensor enclosure contains different water filters, this is because the excess water from the plant goes back into the tank to refill the tank. The filters are because the pump might break if it gets clogged with dirt. This system works very well in drought areas, as well as inside a house or apartment.

4.7.3 Water Pump

The 3.8L 12V Mini DC submersible water oil pump for CPU cooling small pond or HHO system is needs 9-12V DC, with 500mA at 12V to obtain an 8 feet height at 12V, however the PASS project does not need that much height, so it is using closer to 7V, with 200mA. The water input is at the bottom of the tank, with the output attached to either a 7/16 inch Tube. The power is attached as shown in Figure 4.6.3-1, with an octocoupler activated by a signal from the microcontroller, which sends power to a Darlington to produce the necessary current, so it only turns on when the conditions are correct according to the microcontroller.
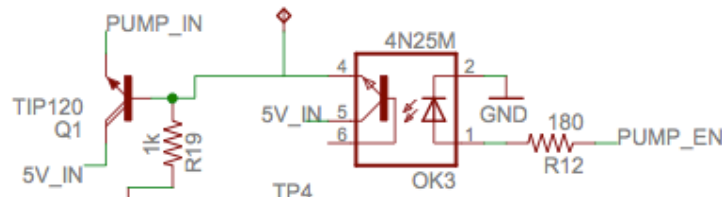
Figure 4.6.3-1;
The connection diagram for the water pump

An open-loop manual device is used during the initial design of the prototype. Timer circuitry is phased in when inputs to the Water pump are more clearly

defined using a closed loop system. Water Pump speed control circuitry for prototype configuration in Figure 4.6.3-2 below:
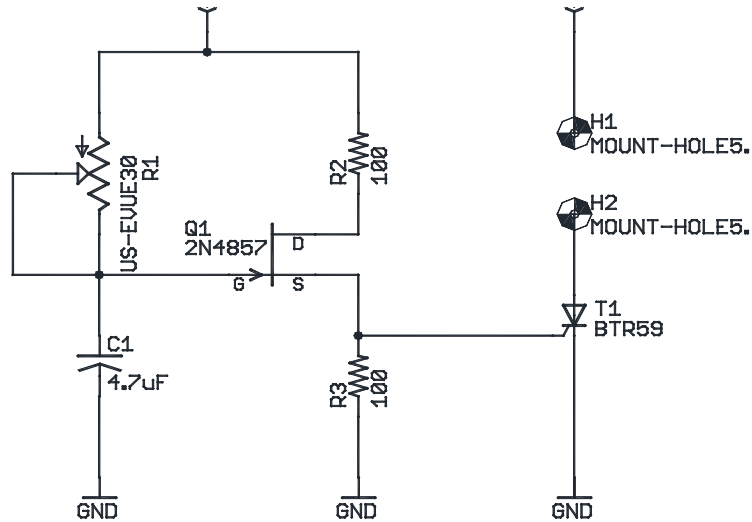

Figure 4.6.3-2;
Pump Speed Control attached to the voltage and ground of Figure 4.6.3-1
*This illustration was drawn using AutoCAD educational software.*

The items listed below in Table 4.6.3-1 are the components required for the breadboard assembly of the speed controller.

Table 4.6.3-1				
Pump Speed Control Parts List				
Part	Value	Device	Package Description	OC_NEWARK
C1	4.7uF	C-USC1005	C1005 Capacitor	99M0595
H1	Mount Hole 5.5	Mount-hole 5.5 5,5	Mounting Hole w/Drill center marker	-
H2	Mount Hole 5.0	Mount-hole 5.0 5,0	Mounting Hole w/Drill center marker	-
Q1	2N4857	2N4857		-
TO18	-	N-Channel Junction FET		67R1086
R1	US-EVUE30	US-EVUE30	Resistor, American Symbol	-
R2	100	R-US_0817/22PO817/22	Resistor, American Symbol	-
R3	100	R-US_0817/22PO817/22	unknown	-
T1	-	BTR59	SOT935 Thyristor	-

4.7.4 Water level sensor

The LS-3 switch from Gems Sensors and Controls has a 2 pin open close connection. Which means it does not require power, if there is an input, as well as a similar output, the water level is empty. Figure 4.7.4-1 shows how the water level sensors are connected to the microcontroller. One sensor is installed with

excess area underneath, so when the water level says empty, it is not truly empty, this is because the pump cannot be run empty. Another sensor is at the top of the tank to notify the user when the tank is full. This adds a factor of error to the system, just in case the microcontroller takes quite a while to deactivate the pump.

| Microcontrolor Digital output pin | Input | LS-3 | Output | Microcontroller Digital input pin |
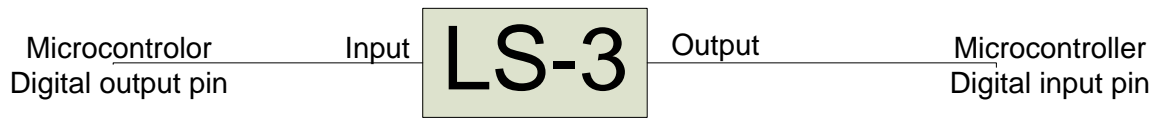
Figure 4.7.4-1;
The connection diagram for the LS-3 sensor

4.8 Power Control and Regulation

This section involves the application of power design and implementation pertaining to the Photovoltaic array, battery, and commercial power rectification. The load requirements are rated at +12VDC filtered, 7.5VDC, 3.3VDC. The -12VDC is not implemented in the prototype or final design. The Texas instruments Webench design tool that streamlines power design implementation with a listing of circuit design and bill of material. The PV controller design and theory of operation will be discussed in detail.

4.8.1 Power Supply Transformer Rating

The rating of the transformer is dependent on the filter and rectifier design, which will be discussed, in another topic. The most common types of input filters use passive components such as inductors and capacitors. With cost and weight restrictions, the inductor filter can be omitted. A lot of power supply designs use a voltage regulator for the reduction of DC ripple and therefore an L-C filter is not used. The capacitive filter is now very common. This section gives a simple transformer design method. The complete power supply design has more components and thus more detail.

The transformer's secondary current draw varies depending on the type of rectification used. The types of single phase circuit designs are half wave (one diode), full wave with transformer center tap (two diodes), and full wave bridge rectifier (four diodes). This project uses the full wave bridge rectifier design.

The half wave rectifier design could be used in the project if there is a need for a simple and inexpensive need for an additional power source. This item produces high current spikes during the capacitive charging stage and the transformer design needs a larger core to avoid saturation which increases the size and weight of the design. This design is rarely used unless the components are readily available. This is not advisable for the microcontroller power source.

The full wave rectifier (two diodes) is the better design choice in the modern era of power supply design. The secondary current waveforms occur twice per cycle compared to a half wave rectifier (one diode). The transformer's secondary

current waveform occurs twice per cycle and is smaller in amplitude due to the capacitive charging. With this configuration the transformer's secondary output is only loaded down half of the time or 50% duty cycle. On the full wave bridge rectifier (four diodes) the transformer's secondary output is loaded full time or 100% duty cycle. With low voltage power supplies the full wave rectifier is used. A transformer with a center tap on the secondary output is required though. The full wave bridge rectifier is used for even higher voltage power supplies and a center tap transformer is not required.

A dual complementary rectifier can be designed if there is a requirement for dual outputs. The two outputs have reversed polarity with a common ground and thus for example -3.2volts DC is required along with +3.2volts DC This configuration is known as a center tapped bridge rectifier.
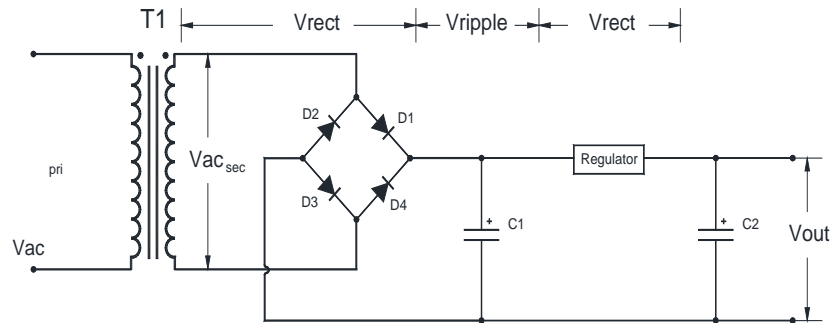
Figure 4.8.1-1; Bridge Rectifier
This illustration was drawn using AutoCAD educational software.

The drawing in Figure 4.8.1-1 uses a capacitive filter plus regulator.
- V_{reg} – the voltage drop across the regulator at 3.25VDC or greater.
- V_{rect} – voltage drop across the rectifier at 1.3VDC or greater.
- V_{ripple} – ripple voltage at 10% peak of the output.

Note: The numbers used are examples and don't apply to the design.
Here is the formula for the transformer's secondary voltage rating below:

$$Vac = \left[\frac{Vout + Vreg + Vrect + Vripple}{1.414 \; x \; 0.9}\right] x \left[\frac{Vnom}{Vlow}\right]$$

The 0.9 is a typical value used for rectifier efficiency. The V_{nom} is the nominal input which is 12VDC at 1.2 amps to operate at a low line voltage at 93VAC. The V_{rect} is 2 x 1.3 = 2.6VDC for the voltage drop on the diode pairs.

$$Vac = \left[\frac{(12 + 3 + 2.6 + 1.2)}{(1.414 \; x \; 0.9)}\right] x \left[\frac{120}{100}\right] = 17.72 \; VAC$$

The VAC can be specified at 17.75. The current rating for the capacitive filter is 1 x 1.2 = 1.2amps rms. Finally the transformer specifications are 17.75 volts at 1.2

amps with 21.3 VAC. This design should be simulated in Multisim or Simulink to verify that the equation was solved correctly.

4.8.2 Power Supply Form Factor

Low profile form factor with a 12 volt input connector via thee solar array is the scope of the initial power supply design effort. The Texas Instruments webench tool is a valuable added resource to this design process. The form factor of this design is targeted to ultra-small form factor system with a displacement of 6 to 9 liters. Some of the individual power elements +3.3v, +5.0v, and filtered +/- 12 volts might have to be relocated to individual sub-assemblies. It would be impractical to include the necessary power modules in the Green House enclosure due to space and humidity concerns. Since the targeted design of this system is a separate power distribution assembly, the maximum displacement of nine liters is a good baseline. The form factor mentioned is not be a rigid requirement for obvious reasons but a starting point needs to be assigned.

4.8.3 Input Power Requirements

In the circuitry design effort, there are some good "rules of thumb" for transistor selection.
- The amount of power a transistor dissipates is proportional to the size of the component. If the transistor is half as big, then it dissipates half as much power.
- The propagation delay of a transistor is proportional to its size. If the component is half as big then it is twice as fast.
- The cost of a transistor is approximately the square of its size. If the component is half as large, then the cost is one quarter less.

These trade-offs seem obvious but can be over-looked in the design process. With the limited budget of this project these rules of thumb saves time, money and minimal redesign. Some important 115 VAC input line requirements are listed below:
- Maximum input level is 135VAC (rms)
- Minimum input level is 105VAC (rms)

For in-rush current limiting, the maximum current when the power is initialized is up to three line cycles and is limited to a level that is lower than the surge rating of the input power cord. The initial design uses a 12 AWG 3 conductor bulk cable.

A repetitive on/off cycling of the AC input voltage should not cause damage to the power supply or blow the fuse. If a problem occurs with this action, there is a manufacturing defect or a design flaw. Also consider the load in use before executing this initial power cycling test. Another important power supply requirement is to have an "in-line" over current protection in order to avoid unit damage and establish product safety. Specified input fuses should be slow-blow-type in order to prevent unnecessary replacement. A spare fuse holder should be implemented in this design for an unanticipated power surge or spike. The use of a circuit breaker could be an option. Input "under-voltage" is also a concern. The

Texas Instruments Webench design tool implements this criteria but this requirement should be explored during the prototype testing.

The DC output voltage regulation needs to adhere to specific ranges shown in table 4.8.3-1 listed below:

Table 4.8.3-1					
D.C. Output Voltage Regulation					
Output	Range	Min	Nominal	Max	Unit
+12VDC	+/- 5%	+11.4	+12.0	+12.6	volts
+5VDC	+/- 5%	+4.75	+5.0	+5.25	volts
+3.3VDC	+/- 5%	+3.14	+3.30	+3.47	volts
-12VDC	+/- 10%	-10.80	-12.0	-13.20	volts

For a typical power distribution model, power requirements varies according to types of processors, memory, extra card slots, peripheral components, along with advanced graphic support. Table 4.8.2-2 is a typical Power Distribution to model a 180 Watt device in amps.

Table 4.8.3-2			
Typical Power Distribution to Model 180 Watts (Values In Amps)			
Output	Current (Min.)	Rated Current	Current (Max.)
+12 VDC	1.0	13.0	14.0
+5 VDC	0.3	8.0	-
+5 VDC	0.5	5.0	-
-12 VDC	0.0	0.3	-

For power limit and hazardous energy levels it is advisable under normal or overloaded conditions that no output shall continuously provide more than 240 VA under any conditions of load including short circuit, per the requirement of UL 1950/CSA 950/EN60950/IEC 950 specification. The 120VAC – 12VDC power supply will be used in the event that the battery is fully discharged and power is required by the system.

The 3.3 VDC power supply design is the main power rail for the MSP430F5342 MCU. Here is a pictorial below for the 3.3VDC Power Supply in Figure 4.8.3-2.The assembly housing is waterproof and is commonly used for automotive applications. The efficiency rating of this device is at 96% and doesn't follow the characteristics of a common linear regulator. Another favorable characteristic is the low heat dissipation. In conclusion this unit has overload / over-current / low voltage protection for system reliability.

Figure 4.8.3-2;
Illustration of Buck-Down Regulator Assembly

This regulator is described as a Simple Buck-Down Power Module that provides a DC-to-DC step-down transformation. This projects design requirement is to convert a battery voltage of 12VDC down to processor voltage of 3.3VDC. The IC package can either be machine soldered or soldered by hand. The main components in this regulator are a linear regulator, and timer circuitry. The 7.5 VDC power supply is the prime power source for the active sensors and the pump assembly.

4.8.4 PV Controller Design

This is an old Ham Radio design project used in the ARRL handbook 2007. The article mentions that there is nothing special about this circuit. Part values can be freely substituted but have resistor values at 1% tolerance. The original project is used as a guide during the prototype portion of the PV controller build. In the theory of operation of the proposed circuit design, current from the solar panel is controlled by a power MOSFET. This design analyzes the tradeoffs between using an N-Channel MOSFET and a P-Channel MOSFET. ESD safeguards need to be employed when handling these components. The N-Channel device is commonly used. Current from the solar panel is routed directly to the MOSFET lead.

N-Channel power MOSFETs might have very low RDS_{on} and also have a lower price, which is again important for a limited budget. Switching the current flow on or off in this application requires an N-Channel MOSFET to be at a 10V threshold above the "rail" it is switching. For example, this 12V design application's gate voltage needs to be at minimum 22V in order for the MOSFET to be activated. This aspect did not currently work with this project's design criteria. If the gate voltage doesn't meet the 22V requirement, the component is at a "semi-active" state. This would be a good simulation set-up in Multisim software in order to reach acceptable switchover operation. The Multisim simulation verifies acceptable voltage and current levels were received during the prototype stage. When this component is in the "semi-active" state, the MOSFET operates in its linear region. This would ruin the component or making it unserviceable. The

diode between the MOSFET and the battery output prevents stored energy or current from the battery flowing back to the solar array at night. The resistors at R1 and R2 are configured as a voltage divider in order for the OP-Amp to operate at an acceptable input level. The potentiometer at R8 fine-tunes the reference voltage level. The R3/C2 network is an input filter, which bypasses any unwanted noise through the battery lines. The diode at D5 is used to protect the OP-Amp just in case the battery is hooked up backwards. Having keyed power connection plugs reduces this hazard. When the battery is below the reference point of 11.5 volts or an adjusted reference point, this biases the Q1 transistor on and illuminates the LED at the collector. The state of Q2 is also biased on which pulls the gate of the MOSFET to ground. When the battery is at an acceptable charged state the referenced input to the OP-Amp's output goes low and Q1 and Q2 are biased off and the LED is off and the MOSFET at Q4 is off. The regulator at IC1 establishes eight volts to the timer at IC3. The capacitors at C1, C3, and C4 are filters that remove unwanted noise. The RC time constant of 4 seconds is established by components R17 and C10. This time constant is the off time. The timer is used for pulsed charging time of the battery. The drawings below in Figures 4.8.4-1 and 4.8.4-2, with table 4.8.4-1 showing the BOM for the Figures; the Figures are to establish the initial circuitry for this design.
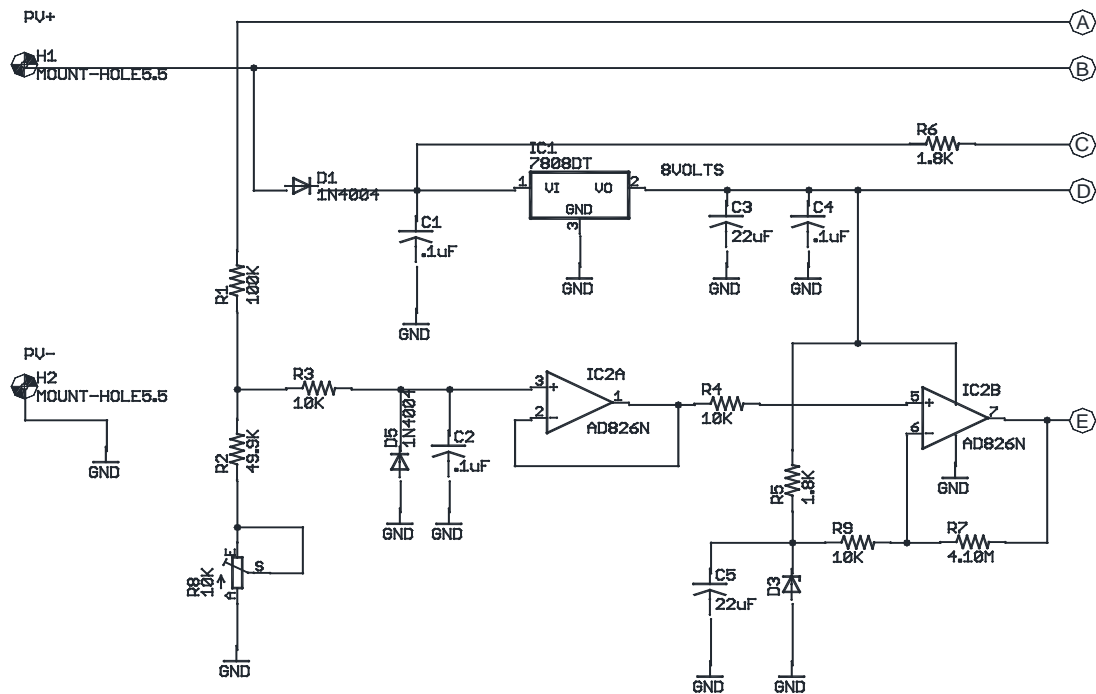
Figure 4.8.4-1;Photovoltaic Controller
This illustration was drawn using AutoCAD educational software.
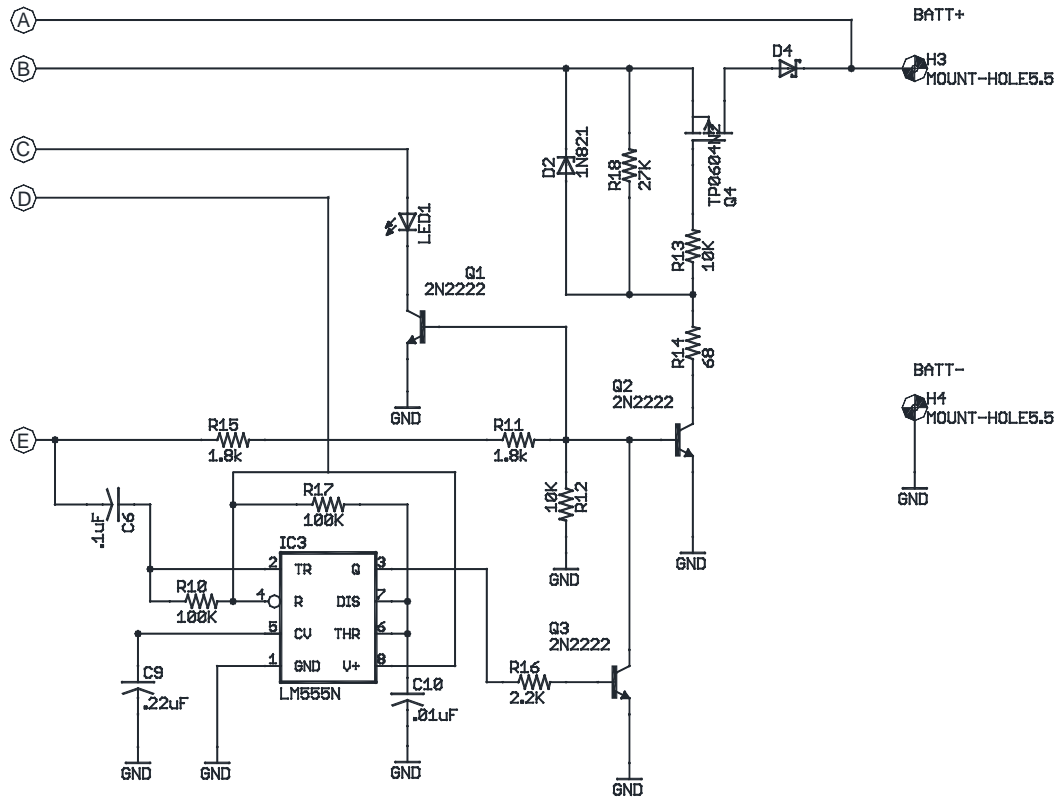
Figure 4.8.4-2;Photovoltaic Controller Part 2
This illustration was drawn using AutoCAD educational software.

Table 4.8.4-1			
Photovoltaic Controller Parts List			
Part	Value	Device	Package Description
H1	-	Hole Mount	Hole, Mtg 5.5mm
H2	-	Hole Mount	Hole, Mtg 5.5mm
R1	100K	Resistor	Resistor, ½ Watt, 1% tolerance
R2	49.9K	Resistor	Resistor, ½ Watt, 1% tolerance
R8	10K	Resistor	Resistor, ½ Watt, 1% tolerance
D1	1N4004	Diode	Rectifier Diode
R3	10K	Resistor	Resistor, ½ Watt, 1% tolerance
C1	0.1uF	Capacitor	Polypropylene Film
D5	1N4004	Diode	Small Sig Switching Diode
C2	0.1uF	Capacitor	Polypropylene Film
IC1	7808DT	Dual Op Amp	-
C3	22uF	Capacitor	Cap, Electrolytic 16V
R4	10K	Resistor	Resistor, 1% tolerance
C5	22uF	Capacitor	Cap, Electrolytic 16V
C4	0.1uF	Capacitor	Polypropylene Film
R5	1.8K	Resistor	Resistor, 1% tolerance
D3	LM336Z-5.0	Zener Diode	Zener Diode, 5V
R9	10K	Resistor	Resistor, ½ Watt, 1% tolerance
R6	1.8K	Resistor	Resistor, ½ Watt, 1% tolerance
R7	4.1M	Resistor	Resistor, ½ Watt, 1% tolerance

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Table 4.8.4-1 continued			
C6	0.1uF	Capacitor	Polypropylene Film
R15	1.8K	Resistor	Resistor, ½ Watt, 1% tolerance
R10	100K	Resistor	Resistor, ½ Watt, 1% tolerance
R17	100K	Resistor	Resistor, ½ Watt, 1% tolerance
IC3	LM555N	Timer	Integrated Circuit
LED1	-	LED	LED, 5mm
Q1	2N2222	Transistor	NPN Transistor
R11	1.8K	Resistor	Resistor, ½ Watt, 1% tolerance
R16	2.2K	Resistor	Resistor, ½ Watt, 1% tolerance
R12	10K	Resistor	Resistor, ½ Watt, 1% tolerance
Q3	2N2222	Transistor	NPN Transistor
D2	1N821	Zener Diode	Zener Diode, 20V
R18	27K	Resistor	Resistor, ½ Watt, 1% tolerance
Q2	2N2222	Transistor	NPN Transistor
Q4	TP0604	MOSFET	p-Channel MOSFET
R13	10K	Resistor	Resistor, ½ Watt, 1% tolerance
R14	68	Resistor	Resistor, ½ Watt, 1% tolerance
D4	SB520	Schottky Diode	Schottky Diode, 20V, 5A
H3	-	Hole Mount	Hole, Mtg 5.5mm
H4	-	Hole Mount	Hole, Mtg 5.5mm

4.8.5 Solar Tracking Device

A solar tracking device with an illustrative side view depicted in Figure 4.8.5-1. The precise mechanical overhead view of the platform is displayed in Figure 4.8.5-2. This subassembly is a movable platform for 2D tracking, and can provide approximately 50% more power than a fixed array configuration. However a full view of the horizon is needed in order for this design to be effective. Table 4.8.5-1 lists the various parts associated with this subassembly. The most expensive items are the plywood and the stepper motor. The board located on the top of the drawing is circular approximately 30 inches in diameter. The bottom board is a square section 48 inches by 48 inches. The item numbers increases as the prototype is implemented.

PV/Solar Array Tracker
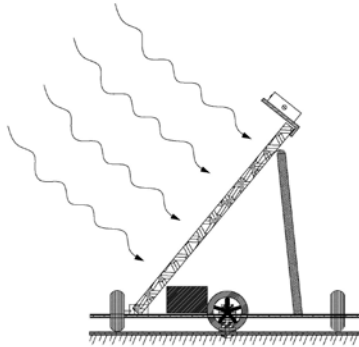
Figure 4.8.5-1; PV/Solar Array Tracker
this illustration was drawn using AutoCAD
educational software.

Solar / PV Tracker
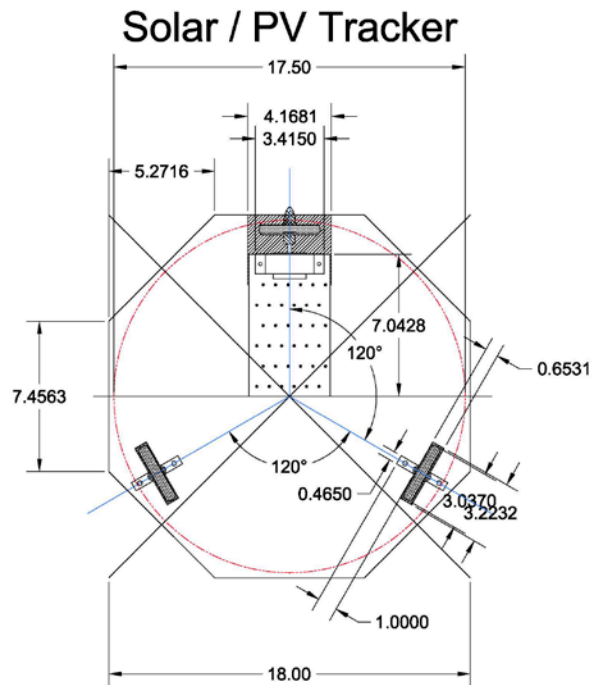
Figure 4.8.5-2; PV/Solar Array Tracker Platform
this illustration was drawn using AutoCAD educational
software

Table 4.8.5-1							
Photovoltaic Tracker Parts							
Part	Qty	Device	Package Description	Vendor	P/N	Price	Total
1	2	Plywood	4 ft x 8ft x 3/8in Plywood	H. Depot	166022	$23.97	$47.94
2	1	Crg Bolt	½ x 8 in. x 8in.	H. Depot	CBLT	$1.93	$1.93
3	3	Hex Nut	½ Hex Nut	H. Depot	Nut 1/2x8	$0.40	$1.20
4	2	Flt Washer	½ in Cut Washer	H. Depot	C.WSH 1/2	$0.20	$0.40
5	2	L. Washer	½ in L. Washer	H. Depot	LWHR 1/2	$0.21	$0.42
6	3	Caster	1-1/2 Rub. Wh. Caster	H. Depot	390003494905	$3.83	$11.49
7	2	N. Washer	½ N. Washer	H. Depot	202210267	$0.67	$1.34
8	1	S. Motor	12 – 36 VDC	MKG	NEMA14	$39.95	$39.95

In the original credited design a Picaxe micro-controller was used. However this design can be modified to use the MSP430 or perhaps an ATmega328 custom designed board that is comparable to the Arduino design. An ATTiny85 works for the prototype design. A DC stepper motor shown in Figure a, could be used instead of taking the risk of modifying an RC servo unit. An initial RPM needs to be established that accurately tracked the sun during the day. Stepper motors operate at 2,000 RPM or less in comparison to brushless motors that run at higher speeds. There are various types of stepper motor technology, which can be categorized as good, better, and best in quality. One type of stepper motor is the CAN Stack stepper motor. This item is constructed from sheet metal parts and thus has simple construction and offer very low torque output. A better quality stepper is the hybrid motor. These are manufactured with machined parts, with high resolution; pole counts which results in higher torque. The higher resolution, pole counts, construction resulted in less typical top end speed. Higher number of commutations per revolution in the motor result from the higher pole counts. The losses begin to add up at higher speeds and more heat is generated compared to a brushless motor, which uses a lower pole count that let it run faster. The next type is a stepper motor with disc magnet technology. This design stands out since a disc magnet is used instead of cylinder magnet. Spinning a disc instead of a cylinder has reduced the inertia of the motor. When using less magnet material, there is less output torque and this is the tradeoff when comparing the disc magnet to the hybrid motors. The hybrid motor cannot operate past 2,000 RPM. The disc magnet stepper motors can easily run at 5,000 RPM and smaller motors can reach up to 10,000 RPM. The stepper motor criteria for this project is to have high-end torque but high RPMs are not require since tracking the sun doesn't require a lot of speed. Most stepper motor designs are typically run in open loop conditions. Therefore the design standard is to add a safety factor which de-rates the torque / speed specifications. For example, if an application needs one millimeter of torque at 1000 RPM, the motor can be sized up to two millimeters of torque to make sure the motor moves reliably.

This design uses a closed loop system eventually since there is feedback from the light sensor tracking the sun. Another big advantage in using a stepper motor is that they can be driven above their rated current draw since they are not normally operating at 100% duty cycle. A typical application runs at about 25% duty cycle. A typical interface setup with a stepper motor is shown below in Figure 4.8.5-3.
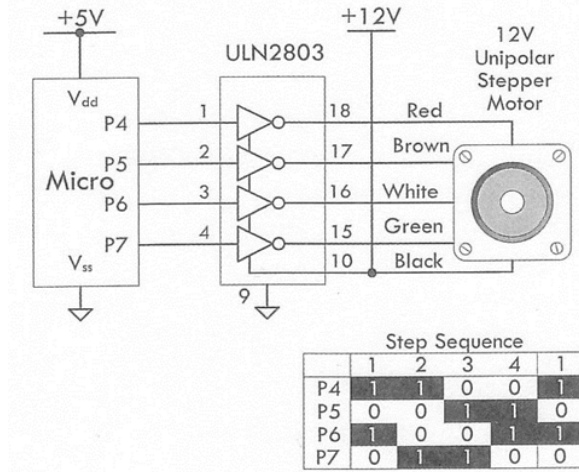
Figure 4.8.1.5-3; Stepper Motor Control
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PRACTICAL ELECTRONICS for INVENTORS.
(Monk, 2013)

The image in figure 4.8.1.5-4 shows the final constructed solar tracker. Below that is an illustration of the tracker connectivity depicted in figure 4.8.1.5-5 which shows the stepper motor, motor driver and sensor. There are two cable assemblies feed to the sensor from the Adafruit motor driver. The two assemblies consist of signal feeds and power feeds. The three LDRs (Light Determining Resistors) are represented here as Left, Front, and Right mounted devices of the sensor chassis.

Figure 4.8.1.5-4; Final Solar Tracker Assembly

PASS Sensor/Tracker Assy Connectivity Schematic
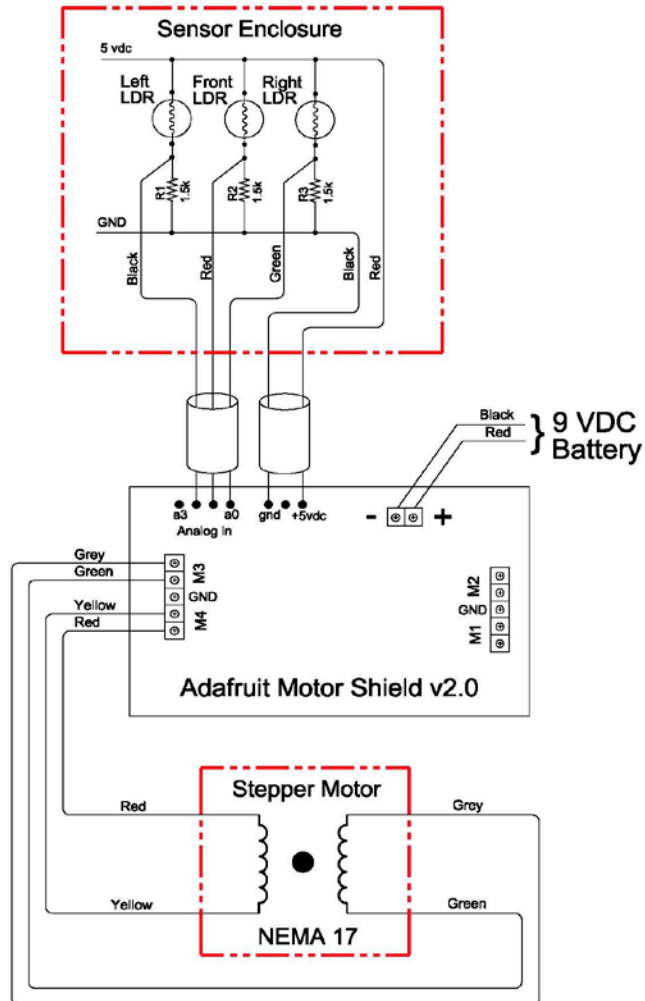
Figure 4.8.5-5; PV/Solar Array Tracker Platform
This illustration was drawn using AutoCAD educational software

4.8.6 Battery Design

The PASS is a low power application. The components that consume the most power are the pump and light. It is very unlikely that these devices will be activated simultaneously. However, since these devices operate by 12V, the battery should be rated at least 12V. Another requirement is that the battery selected needed to be rechargeable, since the solar cell will recharge it. Also, it is desired that the battery store as much energy as possible, since energy is the product of voltage and ampere-hours (yielding joules), these two specs were scrutinized in selecting a battery. Since the project is to be portable, the device must be light weight and compact. The battery is the heaviest component of this

project. A lead acid battery was considered but it is too heavy. It was difficult to find a small, lightweight battery that's rated for 12V and at least 9 Ah. The Bioenno battery was selected based on these specifications, it was rated at 12 V and 15 Ah. Just as importantly, the battery was 3.15 lbs, with length, height and width (in inches) of 5.92, 3.94, 4.02, respectively.

Compatibility issues between the charge controller, for the solar cell, and battery are inevitable. However, Bioenno also sells a charge controller that is fully compatible with the battery. Since this would allow the group to circumvent the time and stress involved in troubleshooting the Bioenno charge conroller was selected. The battery was $ 100 and the charge controller was $60.

5 Design Summary

The design methods the group employed were to attain functionalities that would ensure the device would reach the proper objectives addressed at the beginning of this document. The device is comprised of a power system, water system, sensor feedback network, the microcontroller, and the enclosure; which are all shown in Figure 5-1. The design of each system and the design strategy of their resultant integration are to produce a device to promote sustainability, cost, low power consumption. In addition to these critical requirements, several additional features were added to the design to benefit the user; this was especially true of the features offered by the app. Many of the sub-systems have a bearing on the operation of other systems; consequently this affected the resultant design of the device. The design strategy was implemented to offer autonomous operation to ensure viability of the plant. The following sections elaborate on the design methods employed to reach the stated objectives.
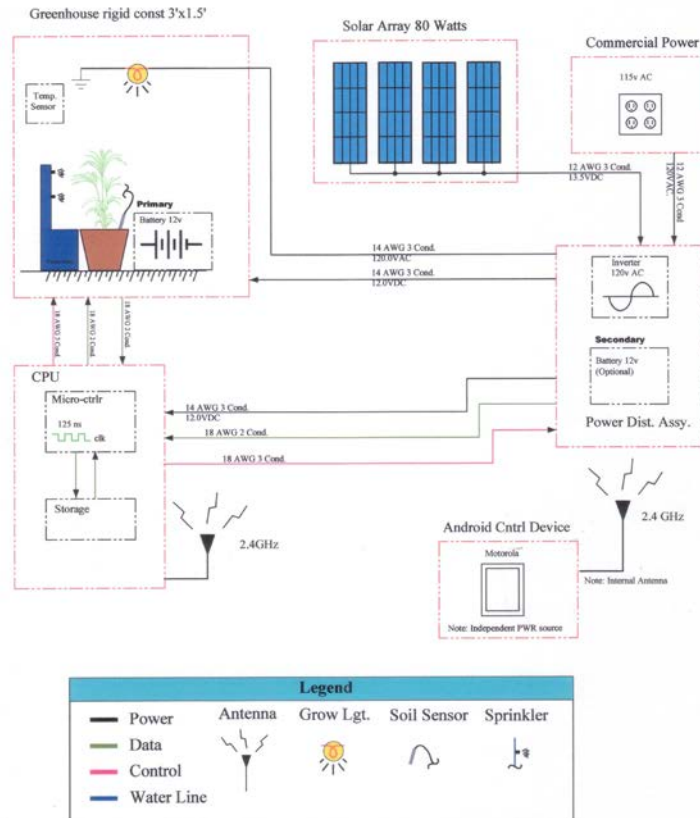
Figure 5-1; System Block Diagram
This illustration was drawn using AutoCAD
educational software.

Emitting adequate light spectra while generating little heat, the Miracle LED absolute spectrum grow light was deemed the most suitable option for the design of this application. Connected to an Edison (E26) mount and consuming 26 watts this efficient, cost effective bulb ensures the plant receives optimal light for viability. The E26 mount is rated for North American domestic applications (120 volts, 60Hz, AC) and has three wires; a ground wire, a neutral wire and a hot wire. Since the E26 is a common, inexpensive socket with a large voltage tolerance its specifications are conducive to the design of the lighting apparatus. The implementation of an inverter was needed for the design of this project. These three wires are connected to the inverter; the current enters the fixture from the hot wire and leave the mount from the neutral wire. The inverter was necessary to convert the DC to AC for the bulb.

The enclosure primarily consists of acquiring optimal housing material and dividing the overall structure into sub-compartments that are properly sealed. The design of the enclosure was to be resilient yet compact and lightweight. Preventing the material from becoming too warm was also a concern; the water in the reservoir was to be about 25°C. This design requirement ensures the plant is not damaged from warm water. To that end, the group selected acrylic as the

material for the housing. The electronics compartment was to be as cool and dry as possible. A major design issue, this compartment was separated from the reservoir to mitigate the humidity that would develop from the reservoir. The final product is shown in Figure 5-2.
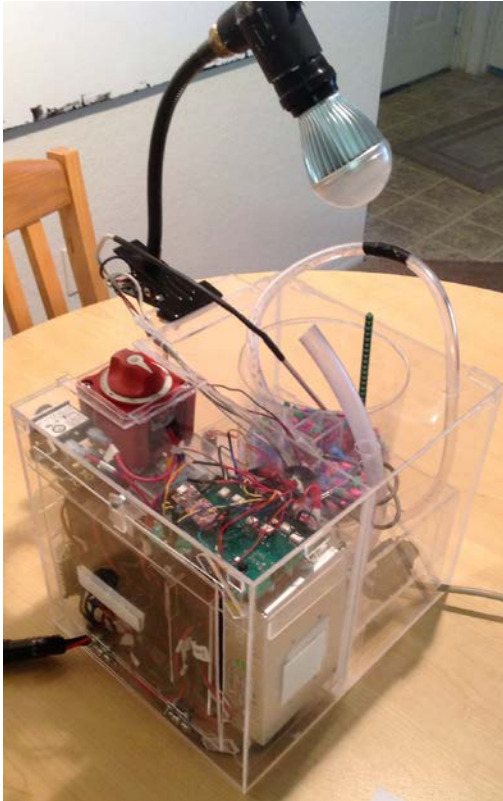
Figure 5-2; Final Enclosure Assembly

The water system consists of the water pump, two water level sensors, and the irrigation system. The water pump only works if the water level sensor tells the microcontroller there is water in the tank. This then triggers the pump to flood the irrigation system. The irrigation system is handmade, with a design that is a mix of drip irrigation systems, soaker hoses, and misting systems. The water pump is a DC power pump, attached to the water level sensor via the microcontroller, with the power to the pump adjusted to meet the GPH needs of the irrigation system. The water level sensor is a DC switch to tell if the water level is okay for the pump. The threshold level needed for the pump depends on the placement of the water level sensor inside the water tank.

Design of the sensor network entails selecting an optimal location for each of the five detectors of the sensor network. The distributed arrangement of the sensors in the device may be considered a network and each sensor, a node within that network. Each sensor is strategically placed in an optimal location to acquire

accurate measured values. The sensitivity, accuracy, range and price of each sensor are factors in the design. The design requirements of this project do not depend on rapid response or sensitive detectors, so the pricing options were expanded to include less costly items, fulfilling the budget effective design requirement. Since the design of the sensor network is based predominantly on feedback, each sensor is wired to the microcontroller. The controller then activates or deactivates a certain sub-system in response to a sensor reading that results from a detected hazard. The user may also be alerted wirelessly of any detected hazard through an elaborate notification system.

The software development can be broken up into two main parts: the microcontroller and user interface application. The user interface is designed to run on a COTS device such as Android or iPhone system. The microcontroller contains a software component that is based off of cooperative multitasking design. This will possess a main control loop, which spawns off the sequences to read sensor measurements, wireless connections, and data management. These sub-software components were first individually tested and then integrated with a final testing procedure to ensure proper behavior and implementation. The user interface application is a page-based mobile application that will be a single implementation that is compatible with modern mobile devices. This is achieved by developing the software project through the PhoneGap SDK, which provides a foundation to produce mobile applications through web development techniques with Javascript, HTML, and CSS. The key requirements for this software component are the wireless communications via Bluetooth link and the data presentation via the GUI. Overall, the design of the software of this project was prototyped and tested in individual units and afterwards it was integrated as an entire piece.

The photovoltaic array is a COTS item that does not require any design work or fabrication. The man-hours to produce and test the array were not be advantageous to the limited project's schedule. The PV/Solar Array tracking device is a simple design with a ground-up design using plywood, carriage bolt assembly, stepper motor and a timing device in order to track the sun's position. An open loop design was initiated first. The next phase in the design was to implement a closed loop system for maximum current draw from the array. The complete power configuration of this project can be generalized into six subjects. These are the sensors, grow light, MCU assembly, commercial power input, Photovoltaic system, and the inverter assembly. The sensor subassembly network might need a voltage divider for optimum calibrated performance. Of course no power input is required for passive sensors. The grow light uses 12VDC, therefor an inverter is not needed.

Design possibilities were mounting considerations, sensor configuration near the inverter exhaust fan, and circuit protection devices. The MCU assembly requires a +3.3VDC power supplied to the Microcontroller unit PCB. The +3.3VDC was designed using Texas Instrument's Webench. The use of filtering devices is

essential to this design since power surges and spikes have the potential to make the MCU unserviceable. The power circuitry on the MCU PCB uses the MSP430FG4618 experimenter's board design concept. A new edition is a Lithium-Iron battery which provides back-up power if the primary 3.3VDC is disrupted. This battery is about the size of a watch battery and is an improvement to using two AA batteries. Enclosure requirements must be determined before protection devices such as circuit breakers or fuse block can be specified.

The commercial power rectifier/power supply has an extensive design. Transformer specifications were calculated in reference to total current draw of the system. A filtering network was established to reduce D.C. ripple. The output of this this design closely resembles a 12VDC battery source. The pump assembly power source design requires a voltage of 12VDC that is used for the speed control. A filter network in the power supply ensures no surges or spikes are present on the pump's input. The filter network also ensures that potential surges or spikes are not reintroduced into the power system via the pump operation. There were no ground-up designs for the inverter and thus a COTS item was furnished. The specification of having a pure sine wave output was also considered.

The photovoltaic assembly has an activation/deactivation controlling device, which provides connectivity to the battery during daylight conditions. This system electronically deactivates the connection to the battery during dusk conditions or when the battery has been fully charged. An illuminated LED indicates that the battery is charging. The critical components are a MOSFET, Schottky diode, and the 555 timers, which makes sure the battery does not discharge its acquired energy back into the solar array. The PV controller unit is a pulsating charging unit using a timer that sets the off cycle at four seconds.

The PCB design process is implemented in one of two ways. The copper runs can be etched by hand or by using a CAD based system. The Eagle version of CADsoft was used to provide PCB design. Once the schematic has been completed with component values set, an automated process generates a Bill of Material. The user can accept each selected component or make a manual selection if specifications are not meet. Once the Gerber files have been generated, the design can be sent to manufacturing for production.

The design requirements for this device are intended for the convenience of the user and the viability of the plant. Power generation and consumption, controllability and data acquisition were among the most pressing design issues. Sustainability, cost and accuracy were among the primary design objectives. Many concessions were made in selecting some devices and design methods over others. Satisfactory design practices also fulfill the goals featured in the objective statements at the beginning of this document.

6 Prototype

The prototype consists of using plywood, Plexiglas, plastic wrapping cardboard, old PCB boards and a good quantity of single strand and multi-strand wire of various gauges. The first step won't be aesthetically pleasing but hopefully functional. This prototype for the plant enclosure PASS project was built with plywood, and other materials that are easy to work with and change. This is to identify where exactly everything should be placed for the final design, including the water tank, and electrical components. The prototype enclosure is built around an existing window planter; a base was added and split into sections for the installation and testing of the electronics and water tank on the bottom. The electronic section was slightly larger than the water tank to allow the battery to be placed in the middle for proper weight distribution, the rest of the section was open and clear to allow free movement to be able to install and change the electronics easily. The water tank area was enclosed with plastic, with a door to the enclosure. This will allow easy installation for the necessary electronics. The tank itself will be a plastic wrapping, with an easy release, to be able to take it out and change anything if needed. Silicone sealant will be used to patch all of the changes inside the tank, to prevent water from getting to the electronics. Building the tank this way keeps it durable, lightweight, yet easy to change with the needs of the system. The sensor specifications are critical for this design. Determining whether these sensors will need to be calibrated is important. Typical trade-offs will be decided on, "Do you want to save time or money?" The CCD camera focal length is an important feature. Due to the confined space of our enclosure, a camera used for security applications did not work for this design application.

The solar tracking device has a base structure made of plywood. More durable composite materials were evaluated after successful operation of the tracking device. The application of a waterproof sealant is desirable in order to prevent the wood from warping out of shape.

6.1 Safety Notice

The most hazardous issue in electronics is household/commercial line voltage at 120v/208v at 60Hz in the U.S. In a typical event, an ungrounded metal object comes in contact with a hot power source, and then an individual touches the "hot object", thus discovering the human body acts as a conducting medium for current that flows to ground. The human body's involuntary muscle contraction due to electric shock prevents an individual from letting go of an energized device. This effect on the human body is extremely dangerous. Voltage and frequencies that are below residential line levels can cause cardiac and/or respiratory arrest as well. The "one-hand" rule is good to observe when using a test probe in an active circuit. This does not permit current flow through your heart via both hands. When troubleshooting equipment with the power off, remember that charged capacitors can still present a shock hazard.

Another safety concern that should be considered during the implementation and design of this project is the electromagnetic/RF interference (EMI). This energy

can not only have a negative effect on circuit performance but it can be dangerous to humans. The importance of shielding and following standards and protocols related to EMI is crucial no matter the scale of the project.

6.2 Sub-System Integration

The first item that needs to be fabricated or purchased is a rigid enclosure. The properties need to be metallic in order to resist noise interference or isolate interference from bleeding over to the other sub-assemblies in the system. This design concept is known as a Faraday cage. Contents of the subsystem will be the PCB, hardware such as machined screws, flat washers, lock washers, board stand-offs, fuse assembly, miniature power receptacle, etc. Proper clearances need to be observed as an example of preventing solder joints from shorting to the enclosure. Power specifications are important not only for the power source design but also for the subsystem design of wire, fuse holders, ground plane of the PCB. Daughter board socket mounts should be part of the mother board design. The daughter board would contain the ATtiny microcontroller assembly. Another aspect that is obvious but overlooked is component lead diameter compared to the hole size on the PCB assembly. This process is of little concern during the prototype phase of the construction but will be a big deal during the final assembly. Cooling concerns and shielding of the microcontroller are considerations that need to be employed in the subsystem integration.

6.3 Part Acquisition

This topic will cover purchasing new parts vs. used parts. Will parts used on the Prototype system be acceptable for the final design? Sixty-five percent of the parts were not reused. The determination of lead time for parts supplied by particular vendors was established. Long lead time had the potential to hinder production schedule. Another criterion was part substitution. The potential for a critical part failure and the possibility that the specified item is obsolete, a subsystem redesign effort might be needed and implemented. This is obviously a worst-case scenario. A secondary vendor list is useful if there are quality control problems or unrealistic price increases. A minimum order requirement by the vendor also affected procurement lead time. Matching the parts specification was of high importance when part substitution is required. The components dimensions and power consumption will be critically important for the PCB design. A critical component design change will or could render the PCB design obsolete. This point is obvious but it can sometimes be overlooked.

Using EAGLE CADsoft for the initial and final design got the parts acquisition accomplished. After the schematic was complete with all the necessary components integrated, the board layout was scanned and an initial bill of material was generated. After this process was used a number of times recognition of components was recognized by the user /designer. The software will select a component by its typical characteristics and the user will be prompt to verify if this is the right component. If the user decides the component does not meet specifications, then this component can be changed by manual selection

with an alternate list of available components. Sometimes the cheapest components available will have a minimum order requirement. The Texas Instrument's Webench design tool has an automated Bill of Material process. Once the initial design was complete and the BOM has been generated, the parts can be ordered automatically through Texas Instruments at very competitive prices.

6.4 PCB Design and Assembly

Creating a PCB assembly involves two types of processes which are draw the design by hand or using a CAD tool. The processes are using an etch-resistant pen, laser printer toner transfer, and sending the Gerber design to a PCB manufacturing facility. The CAD tool approach will be used for the final design since this will be more time and cost effective.

There will be approximately 4 to 5 PCB designs/layouts. The first board will have the MSP430 surface mount chip, push button switch, ADC, and a crystal oscillator for timing. Will implementation of a UART be needed in order to connect to a COTS RS-232 device? Questions like this will need to be considered before the final design is implemented. A reverse engineering approach might need to be considered since these questions came up before with similar designs. Why "reinvent the wheel" when you don't have to. After this process, the elimination of components of the previous design can be considered such as the LCD display, or touch device. There is a possibility that problems will need to be debugged due to unforeseen defects in the PCB design process. A second PCB design might be necessary in order to work out the initial design problems. The flawed designed boards could be used to enhance solder skills. Practice makes perfect. With this being said, PCB layout and theoretical knowledge of DFM (design for manufacturing) is important. Some examples are keeping ceramic-mount capacitors away from the edges of the board. The tricks of the PCB design trade will be critical. Surface mount components can be difficult and this task will require practice. To reduce RFI, PCB should have plated through holes, solder mask. This process is very difficult to do with "home resources".

The other subassemblies will have PCB designs at a smaller less complicated scale. A daughter board mounting socket can be employed on the subassembly PCBs. The PV controller circuit board will be a bit more extensive and of course the UPS unit will have considerable more components. The ambient weather station design might be somewhere in the middle as far as component density.

The most popular software is Cadsoft EAGLE that is available online. JeremyBlum.com is a great website for an instructional video on using EAGLE CAD design software. The video consists of starting a new project which will consist of building the initial schematic of your PCB board. This would be a good instructional start for engineers not really proficient with AutoCAD or ProE. When the schematic design is complete the selection of component values will need to

be added. Eagle comes with an extensive library of components. The instructional video will go through the process of downloading additional components from popular manufactures and vendors such as Texas instruments and Newark. The software will generate a bill of material for the components in your design. A manual selection of components can be made and the software will prompt the user if the selected component is preferred. Getting familiar with the drawing icons will take some time but the learning curve is small compared to most CAD programs.

Most PCB fabricators will accept their, EAGLE, CAD files directly. In the PCB design effort there are two categories which one uses the metric system and the other uses the "imperial system" for defining measurements and establishing dimensions. As an example the "micro-meter" is 25.4 times smaller than the "Mil". In industry, dimensions for electronic manufacturing are trending to smaller scales all the time. With quality concerns in mind, most companies will work exclusively in the metric system. Since this project will not be dealing with vast quantities of PCBs, using the "imperial system" should not be difficult.

The accepted data formats for PCB design data are:
- Gerber RS-274X (Extended Gerber with embedded apertures – by Gerber Systems)
- DPF (Dynamic Process Format – developed by Ucamco NV)
- Gerber RS-274D (Standard Gerber with a separate aperture file – by Gerber Systems)
- Eagle.BRD file (CAD-data from CADsoft now Farnell)

Artwork is defined as all copper layers, legend layers and soldermask, board outline /mechanical layer, SMD paste layers, peel-off layers, carbon layers, etc.

Drilling:
- Excellon (1 or 2) + appropriate tool list (ideally embedded)
- Sieb&Meyer + appropriate tool list (ideally embedded)
- DPF (only true drill data, not a drill map)
- Gerber format RS-274X or RS-274D (only true drill data, not a drill map)

Some important design processes are that only ASCII-encoded files should be supplied. These files are read by personnel such as engineers who can check them visually if needed during the data preparation phase of the process and therefore formats such as EBCDIC or EIA are not accepted. Do not scale your data; all data must be 1:1 or 100%. Use the same offset for all the Gerber layers and the Excellon drill data. The preferred method is not to use any offset at all. All layers will need to have the same offset. Using the same units, either mm or inches, in the Gerber and Excellon output files as in the CAD PCB design drawings will eliminate conversion and/or rounding errors. Use the same resolution/grid layout for the Gerber and Excellon data to provide a perfect match. Another point to make about the grid layout of the output is that it should be at least an x10 factor better than the resolution used in the CAD PCB design

software. For example, if a 10 mil resolution is used to draw a typical board in the CAD PCB design software, then use a 1 mil output grid layout output resolution for the Gerber and Excellon output. Make sure that the provided data is supplied as seen from top to bottom through the PCB. Do not mirror any data layer that is image or drill. The process of viewing the PCB from top to bottom through the board is common practice in the PCB industry. As an example that when viewing the Gerber data, text on the top side of the board (copper, solder mask, legend) should be readable and the text on the bottom side of the board (copper, solder mask, legend) should not be readable (aka mirrored). Place some small text (board identification, project name, etc.) in the copper layers. Make sure the text complies with readability rules. This is another example of avoiding mirroring errors. CAD PCB design data, other than from EAGLE will not be accepted. The reason for this is the following: Converting example AutoCAD data into production data will probably lead to errors which cannot be easily cross-checked. The second reason is it is impossible to have legal copies of every CAD PCB design package in the world market and thus have the intuitive knowledge to use them all correctly.

Gerber is clear and concise. It has been the industry-standard for a long time in the PCB manufacturing market. With this being said, every PCB design package can output Gerber data and this process will be described fully in a typical CAD PCB design package handbook. Checking the accuracy of the Gerber output data can be done by downloading one of the many free Gerber viewers available on the Internet. See for example GC-Preview available as freeware from http://www.graphicode.com.

The PCB design of this project consists of the major components mentioned earlier, such as the MSP430F5342, PAN1326, and optocouplers. The PCB layout follows the schematic shown on the earlier pages. Female header pins mounted to the board via through holes provide the connection between the microcontroller and the sensor devices. A picture of the PCB design is shown in figure 6.4-1 below. One can note the red fill is a power plane and the blue fill is a ground plane located on the bottom layer.
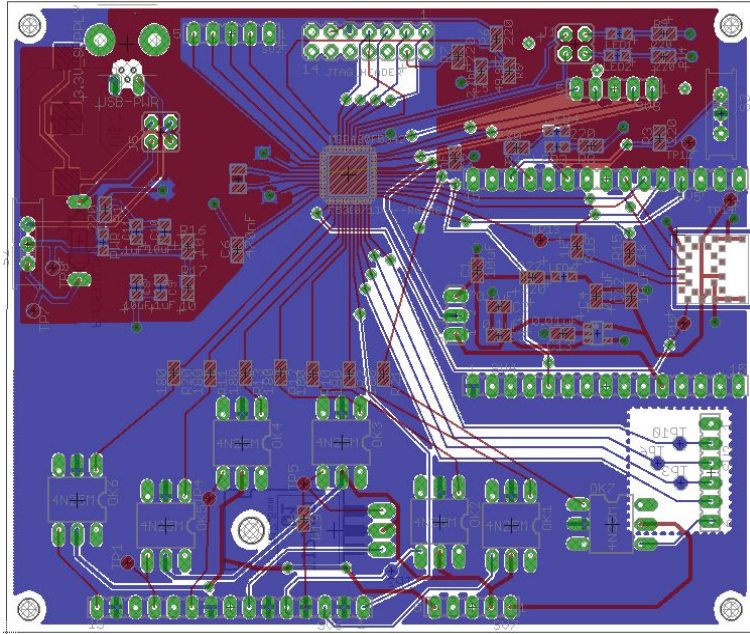
*Figure 6.4-1; Snapshot of the PCB layout
created with CadSoft's EAGLE program*

6.4.1 Soldering / Hot Air Station

Solder is used to join electronic component leads to circuit boards in order to make a physical bond as well as an electrical bond. The solder is composed of tin and lead which defines an alloy. Some applications of solder come with rosin flux at the core. Flux is used to dissolve oxides in order to provide a durable bond and thus avoid "cold solder joints". Applying flux directly to the desired component junction is preferable. Initial preparation must be performed which is to clean all metal surfaces of oils, grease, or wax. These impurities degrade the desired bond. The use of a mild solvent such as alcohol is used to remove unwanted residue. Use a low-wattage iron (25 - 40 watts) when soldering components to a PCB, The use of a Sears's craftsman solder gun is discouraged. A good soldering technique results in a thin, bright layer of solder. The application of a fresh layer of solder to the tip of an iron is referred to "tinning". Another method of tinning is applying a thin layer of solder to the end of wire for application on a PCB. "The trick to making good soldering connections is to first heat the two metal pieces to be joined. Do not melt the solder first; otherwise, you are not able to control the placement of the molten solder. Solder likes to flow toward hot spots". When all the soldering is complete, inspect the work for stray solder beads. In order to protect sensitive components, a height sink maybe required. Solder types are as follows: 60/40 (SN 60) and 63/37 (SN 63).

For 0805 surface mounted components, a hot air station was used. Approximately 35% of the PCB was occupied by surface mounted devices and thus required a hot air station since a soldering iron concentrates heat in a smaller area which may result in lifted circuit pads. The usage of solder paste was needed in this process in order to properly mount the SMDs on the PCB.

6.4.2 De-soldering

When a defective connection is made or a bad component needs to be replaced, the solder joint needs to be melted and removed in order to repeat the original soldering process. Reworking resistor or capacitor components isn't too difficult. The challenge is removing a bad IC without "lifting" the circuit pads. A good technique for "freeing" a component from the solder joint is the use of an aspiration tool which is known as a "solder sucker". The preferred method is the use of "solder wick", which is a copper braid. Apply the wick on the solder joint and place the soldering iron on top of the wick. The application of flux improves the leaching action of the solder. This is described as capillary action. An example when de-soldering is when the placement of SMD LEDs are not oriented in the proper polarity.

6.5 Component Installation in Enclosure

After all of the components are tested separately and as a system, as well as tested within the enclosure for wire length, and placement measurements. Then everything was installed onto the PCB board. Cooling fins will be inserted on top of the microcontroller; this serves two purposes, to keep the microcontroller cooler. It will also keep the conformal coating off the top of the controller, which would not let the heat escape from the chip. Then the PCB board was sealed with conformal coating, to protect the electronics from humidity and water damage during testing. The larger components, like the different sensors and power system components were carefully installed in the enclosure in their measured areas. Then the PCB board was gently put into place.

6.6 System Hardware Integration

This effort should follow after each sub-system that needs integration has been completed and tested. The goal of system engineering is broad but once the subsystems are integrated new challenges surfaced. The individual modules of this project should have "Keyed plug/receptacle" configuration. For example it would be impossible for a power plug to be inserted into a signal receptacle or a dc source doesn't plug into an AC load. These types of "keyed devices are used in most automobile applications. Other applications that can be explored are having plug and receptacle devices embedded into the enclosure device to be integrated. This is also categorized as a "Hot swappable" device. System cable lengths need to meet proper AWG requirements. A chart is located in the appendices in order to meet proper specifications. A sample of this is listed below in Figure 6.6-1:

Table 6.6-1									
Wire Gauge Calculation Chart									
Maximum Current Draw									
Wire Gauge	5 Amps	10 Amps	15 Amps	20 Amps	25 Amps	30 Amps	35 Amps	40 Amps	45 Amps	50 Amps
22 AWG	6 Ft	3 Ft	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
20 AWG	9.5 Ft	5 Ft	3 Ft	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
18 AWG	15 Ft	7.5 Ft	5 Ft	4 Ft	3 Ft	Ins.	Ins.	Ins.	Ins.	Ins.
16 AWG	24.5 Ft	12 Ft	8 Ft	6 Ft	5 Ft	4 Ft	3.5 Ft	3 Ft	Ins.	Ins.
14 AWG	39 Ft	19.5 Ft	13 Ft	9.5 Ft	8 Ft	6.5 Ft	5.5 Ft	5 Ft	4.5 Ft	4 Ft
12 AWG	62 Ft	31 Ft	20.5 Ft	15.5 Ft	12.5 Ft	10.5 Ft	9 Ft	7.5 Ft	7 Ft	6 Ft

The pump speed controls were important during the prototype and final design stage of the project. Experimenting with speed control, a first attempt would be to use a potentiometer. This application would work but a lot of energy is wasted. The action of turning up the resistance in a potentiometer decreases the pump speed but excessive current flow through the pot develops. This process results in wasted power. The best application of speed control is to provide short on/off pulses of the specified pump voltage. The pulses are very fast and thus the motor would not have time to react to the on/off response. The motor ends up averaging the on and off sequences and so the motor receives less voltage.

The term used for pump speed control is pulse width modulation (PWM). This approach is typical for just about all motor speed control circuits in use. The longer the duration of pulses, the faster the motor operates. Smaller pulse duration results in lower speeds. Most motors operate efficiently at 25% or higher pulse width duration.

The integration of the Lithium-Iron Battery connects to the Photovoltaic controller assembly with two connected 12AWG wires. The battery is specified at 12volts at 20amp/hours. The mounting location of the battery has not been specifically determined yet. Precautions must be made to avoid puncturing or rupturing the battery.

PASS Enclosure
Electrical Schematic
23rd April 2014
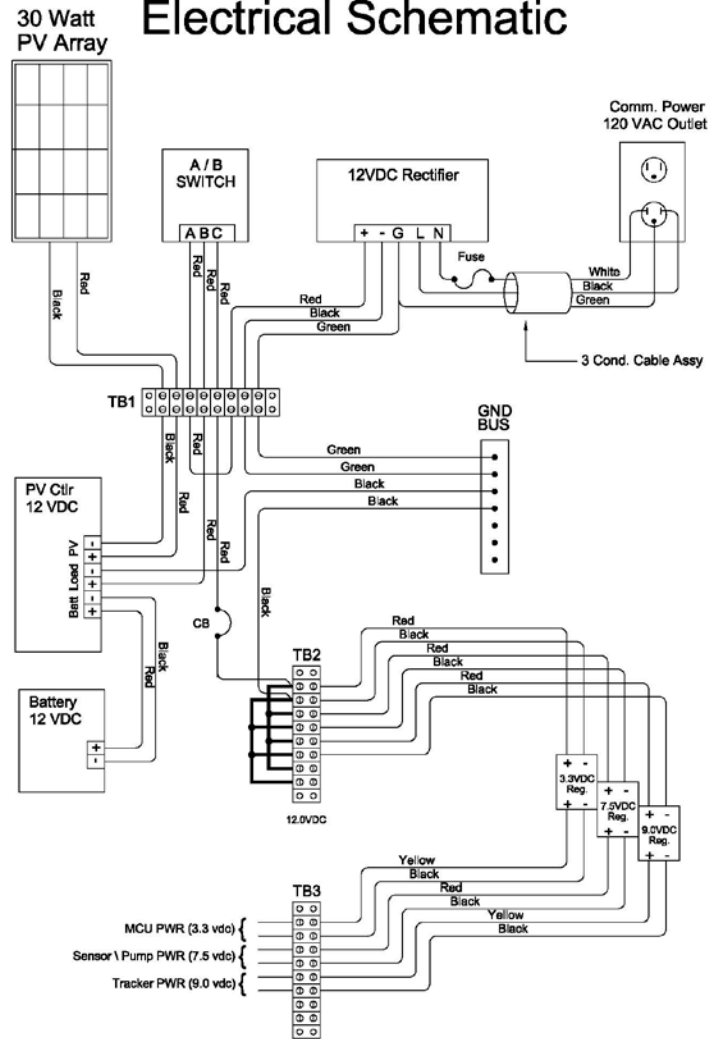
Figure 6.6-1; System Electrical Schematic
This illustration was drawn using AutoCAD
educational software.

6.6.1 Grounding

On most common commercial systems, an earth ground is established by driving a copper rod to a depth of eight feet or greater. This copper rod is then wired to the power source of the device. This step can be eliminated if commercial power is available to the system without a ground fault. The earth ground is categorized as a "single point" ground. This project connects the various modules to chassis ground whether or not this is connected to earth ground. Without this design in place, power fluctuations can occur. The common ground point for individual components will be chassis ground in which all those devices will be connected to a single point. This single point ground is the zero volt reference point. A shock

hazard can be caused in the presence of high voltage, neglected earth ground, and when metal frames are used for chassis ground. The physical connectivity to earth ground at a typical piece of electronic equipment is also through the power cord's ground wire.

6.7 Issues and Compromises

In the power design phase of this project using the Texas Instruments Workbench, tradeoff are noted with cost versus latency of the device. In analog systems latency is not a critical concern so providing a cheaper device would be acceptable. This is not be the case for developing power input to digital processing devices or in some cases communication devices. COTS items were used instead of the ground-up design approach due to time constraints.

7 Testing

System units were measured by exposing them to various conditions and holding any additional variables constant. By recording the resulting outputs and comparing differences, the group determined the cause(s) that contributed to the error. Many ad hoc methods were also developed for testing as each system and component serves a specific purpose. The following serves to illustrate such methods.

7.1 General Check-Out Audit

In the distant past a simple volt-ohm-meter (VOM) could troubleshoot most electronic problems or "bugs". Now with the use of modern circuits that require advanced digital techniques, precise readouts and higher frequencies, test and equipment requirements have changed."

Circuit testing required some user knowledge of what is to be measured. Using an oscilloscope and multi-meter was determined. Another question asked is what is the accuracy requirement of the circuit under test? All these concerns are good to know. The advantages of Digital Volt Meters (DVM) are a high input resistance that is approximately 12Mohms, low price, good precise reading, and portability. The big disadvantage is that the display updates can be slow. Will this project need to use the National Institute of Standards and Testing (NIST) data for battery voltages? Probably not but this will be good knowledge to have if suspicion of faulty readings from a DVM during a routine test. A good back up device would be an analog VOM like a Simpson model 260.

The measurement of frequency and time will probably not be of great concern. This opinion might change when the prototype has been built. In Figure 7.1-1 below this is the configuration that PASS requires in order to achieve accurate and reliable readings on an Oscilloscope:
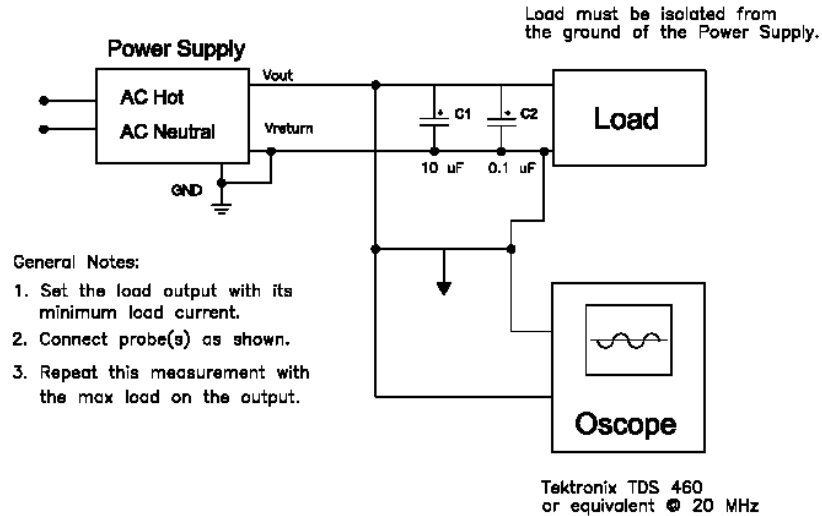
Figure 7.1-1; Testing with an Oscilloscope
This illustration was drawn using AutoCAD educational software.

In the testing portion of the design basic laboratory skills will be necessary. ESD awareness should be applied to the test procedure at hand. This employed a wrist strap and an antistatic mat for PCB assembly.

Testing can be defined by three categories:

1) INCO initial check-out
2) Dry Run Test
3) Formal Test (For industry use)

The INCO testing is the simplest and therefore brief procedure which checks the basic operation of the stand-alone components or sub-assemblies. The use of a multi-meter, oscilloscope, or device readout to check for basic manufacturing requirements has been met at the sub-assembly level.

A dry-run test is usually an initial test of a completely configured system with all the individual components in good working condition. This test will be executed with anticipation that certain anomalies will occur from the system integration process. Debugging and corrective action is taken and the dry-run process is repeated until all anomalies are solved.

The formal testing is performed when the design engineer has confidence in the system and the test is a formality. This test is normally a requirement for government-contracted systems. Quality control personnel and project engineer will usually witness the formal test data in order to have the system certified a deliverable system. This type of test will be initiated prior to delivery of final report.

Ripple and noise are classified as periodic or random signals over a frequency range of 10Hz to 20MHz. An output table is depicted below. The outputs under

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test should be bypassed at the connector with a 0.1 micro-farad ceramic disk capacitor and a 10 micro-farad electrolytic capacitor to simulate system loading. Compare results listed in Table 7.1-1 below.

Table 7.1-1 D.C Output Noise/Ripple	
Output	Max Ripple(mVpp)
+9.0 VDC	50
+7.5 VDC	50
+3.3 VDC	50
+12 VDC	120

7.2 Troubleshooting and Repair

Having working knowledge of the circuit or system under repair is fundamental. The most common types of instruments used are the VOM, DVM, logic probe, and the Oscilloscope.

The more expensive equipment like a spectrum analyzer or logic analyzer was rented instead of purchase since these items impacted the budget. Obvious equipment malfunction can be noticed without expensive test equipment. Looking for broken wires, burnt components are common component errors. The two most common methods of troubleshooter is signal detection and signal injection. The signal detection method commonly employs the use of an oscilloscope. Use a capacitive probe in order to neutralize DC current levels. Turn the power source off when making resistance level checks with a DVM. When there is a heating problem with a suspected component a "cooling spray" would be applied and the component would start working again. Of course this component needs to be replaced. Power levels should be the first area under test. This procedure is the most obvious but can sometimes be overlooked.

7.3 Logic Testing

For digital applications, testing equipment that can be used is the oscilloscope and the logic probe for simplicity of this discussion. Logic analyzers and computer operated test devices are other applications that can be explored. Remember that ESD precautions must be observed so the device under test is not damaged and rendered unserviceable.

The requirements for an oscilloscope are that it must have dual trace capabilities for measuring inputs and outputs of a device at the same time. This becomes evident in upcoming categories. The first testing criteria, is measuring the circuit clock pulse in relation to memory wave forms. This is known as "clock timing relationship." Comparing amplitudes, shapes and timing are considered "I/O relationships." A good example of this is on a typical oscilloscope in which one channel is inverted compared to the second channel and an "add" function is selected in order to compare the difference in amplitudes. Selecting the right type of scope probe is critical as well. If only one 10X probe is used then the I/O result was incorrect. Another method is using a reference frequency for channel 1 and

comparing the output signal with the leading edge or trailing edge is an example of "frequency-division relationship."

As mentioned before, the selection of a scope probe is important along with using a grounding clip for this item. Noise can be induced into the scope display, which results in inaccurate readings.

7.4 Sensor Testing Methods

Before the testing process can begin, knowing what the physical properties and specifications of the sensor under test is important. Does this component need to be calibrated? If the answer is no, then perhaps low level testing can begin. If yes is the answer is yes then informal testing was solely used for data collection. An environmental chamber would be the optimum place for conducting such tests.

There are two types of test and they are destructive and non-destructive testing. Since this project does not directly affect public safety and due to the limited budget, all testing was in the non-destructive category. The test used examines a sensor in order to detect imperfections or determine properties without degrading its function. The specifications of the component under test was defined the test criteria such as target values and operable limits defined as tolerances. With this being said, the specification sheet was the driving force of the utilized test plan. The degree of accuracy was taken into consideration with a temperature sensor. The initial check-out (INCO) of the temperature sensor can be as simple as placing two fingers on the temperature sensor and observe the voltage /current reading to see if it is increasing. The next step was to apply an ice cube to see if the reading decreases. This is of course a very informal test in order to have confidence in the components be used for the prototype. Also this practice won't test the full range of the device but this again was acceptable for prototype use. Other more controlled tests would be the use of a heat gun and a can of refrigerant. The refrigerant would need to be environmentally friendly in order to be compliant with EPA clean air act regulations. The use of a laser temperature gauge to the tenth degree would be acceptable for this project. The analysis of the test data falls under the topic of quality control. It would be a good idea to have extra sensors of the same type for data comparison. In typical industry operations, the inspection and testing fall under quality control. Histograms are sometimes provided to show captions of test results compared with specifications at hand.

7.4.1 Moisture Sensor

The testing method for the Vegetronix VH400 soil moisture sensor was separate from the system, because the voltage changes due to the soil type, as well as the moisture, the sensor was attached to a DC power supply and an oscilloscope. There were cups with the same amount of soil; this soil is the final soil choice for the project. These cups had different amounts of water; there will be a dry cup, and a very wet cup to tell the outer limits for the sensor. There were also cups with slightly dry soil, moist soil, and over moist soil. There were 5 different cups

for the moist tests, with 8oz of soil each. One cup had 3oz of water; the others have 2.5oz, 2oz, 1oz, and no water. This process found what the threshold voltages are for the moisture sensor output as shown in Table 7.4.1. The thresholds needed are whether or not the soil is too dry and needs to be watered, when the microcontroller can send a signal to stop watering, and when the temperature is too hot, what the thresholds are for watering to cool off the plant. Since the sensor can handle different voltages the different voltages will also be tested. The power supply cannot supply more than 12volts, but the sensor can take 3.3 to 20VDC, but everything under 12V is not an option for the PASS project. Therefor the thresholds were tested with different input voltages and currents as well as different moisture types. This showed that the output did not change from 4-12 volts. When the prototype is built the sensor was tested again, which showed no change from previous testing.

Table 7.4.1; Limits	
Output	Logic limit
< 1V	Needs water
1 < x < 1.3	Damp
< 1.3V	Do not Water

7.4.2 Temperature Sensor

The Vegitronix temperature sensor was tested to verify equation A. Multiple temperature points were tested. It was done with a DC power supply and an oscilloscope and multi-meter. The results were compared with a chemical based thermometer.   The different temperatures will be simulated with hair dryers and cups of ice, since both the thermometer and sensor are weather proof; the sensor needs to be at a stable temperature for 15 minutes to properly test. This is because it is weather proof, so all of the sealants around the sensor prevent accuracy when temperature outside the sensor is rapidly changing. The tests were done with the comparable items measuring points as close as possible. This will be to prevent error because of the simulated temperatures being different in different areas. The sensor was tested at different voltages, since the requirement for the sensor state a range of 3.3 to 20VDC, but the power supply can only handle up to 12VDC, so the equation will not only be tested against a chemical thermometer, it will be tested at different voltages to see if the output changes depending on the input. The conclusion from the testing was that the output did not change when the input was from 4-12 volts and the equation is correct for the temperature.

$$Temperature\ in\ deg\ C = \ ouput * 41.67 - 40$$

7.4.3 Photo Sensor

The photo sensor was tested using a few methods. As previously mentioned, the photo sensor is to activate the lighting assembly only during the day in the absence of light with a wavelength of 750 to 950nm. A simple visual inspection of determining if the light activates during the night was sufficient for that period of time. During the day, the light sensor will be shaded to determine if the lighting assembly is activated. If the light sensor falsely activates the assembly, the sensor will be checked as well as the conditions that are related to the light sensor in the program software. The photo sensor must not detect light form the grow light. To determine the undesirable detection of light from the artificial light source, a log was created based on activation times of the grow light; any anomaly will result in moving the grow light or sensor.

7.4.4 pH Sensor

Testing of the pH meter consisted of acquiring four buffer solutions, each with a different pH and obtaining a sample at a specific temperature. One buffer will contain a solution with an acceptable pH for the plant (about 6 pH) and the other two solutions contained solutions with pH values (outside the 5.5 to 6.5 range) that would send an alarm wirelessly to the user. For this project, the temperature was $25^{o}C$ (room temperature). The output was not the corresponding pH value of the buffer but whether or not an alarm is sent to the user's wireless device. If the pH value sent a false alarm or does not send an alarm when it should, the configuration of the pH meter to the controller was checked. The voltage levels from the pH meter were examined and the current and voltage characteristics of the operational amplifier and the ADC, if possible, were examined. A log was created to list tracked values and any anomaly will be further examined and traced. This test allowed us to determine the reliability of the pH meter, the proper operation of the pH op-amp circuitry to the microcontroller, the microcontroller program that processes the information from the meter and also the transmission of the wireless signal that resulted from an undesirable pH reading.

7.4.5 Light Assembly

The lighting unit includes the actual assembly that holds the grow light and the actual grow light as well. Among the values tested for desired operation include the voltage sent to the E26 lighting mount, the color temperature of the light, and the heat the light generates. A multimeter was used to obtain a required voltage of 120 volts from the E26 light mount, if the multimeter did not record this value within a margin of (+/-5 volts), the power distribution was to be evaluated for diagnostics. The color generated from the grow light was tested via a pocket photometer, if this value was unsatisfactory, it potentially may be caused by an improper voltage supply. Consequently, the leads to the mount were checked as well as the power source. To determine the heat the plant is exposed to a temperature measurement form the location of the plant was acquired for testing. Depending on the ambient temperature, the temperature reading was desired to be within a range of ~20 to $35^{o}C$, if the measured value was outside this range,

the height of the light was adjusted. The color temperature of the grow light was required to be 3000K; this value too was checked with a handheld light meter.

7.4.6 Enclosure

Among the various areas and characteristics tested in the enclosure of the device include the temperature of the water in the reservoir, the temperature in the electronics sub-compartment and the humidity in the electronics sub-compartment. In addition to determining if the enclosure is properly sealed, these readings will examine if the proper material was selected for the enclosure (it was explained in the research and design portion of this document that temperature inside the enclosure is related to the type of material used to produce the enclosure). The operation of the cooling fan and the dehumidifier in the electronics compartment were also tested. During testing the required values were measured with a thermometer, the following conditions must be reached for successful checkout:

- The water in the reservoir was to have a temperature in the range of 20 to 30°C
- The temperature in the electronics compartment is to be no greater than 80°C and the relative humidity must be below 90%.
- Since the fan activates periodically, its operation will be timed onsite. The dehumidifier will be tested by checking the on-board dehumidifier indicator.

7.5 Water System

Within the water system the pump and water level sensor will be tested separately at first. This will be to identify the lowest possible power consumption, while the components still work for the requirements. Then the pump in the ideal conditions will be tested with the irrigation system. The irrigation system will be tested to find out the ideal build specifications. This will also test the pump to see if the earlier ideal conditions still work. The water tank will not be tested.

7.5.1 Water Pump

The 3.8L 12V Mini DC submersible water oil pump for CPU cooling small pond or HHO system was tested outside, attached to a DC power supply, submersed inside a bucket of water with the output hose attached. The test was to see how low the DC voltage can be and what kind of current is required for the pump to still function at a lower rate than the specifications, which say that at 12V the max height is 8 feet, and the PASS project does not need 8 feet of height, and would prefer to supply the least amount of voltage possible to conserve the battery life. The results of the testing conclude that the pump can be run with a voltage as low as 5volts for the PASS project, it does need around 200mA of current at that voltage as well.

7.5.2 Water Level Sensor

The LS-3 water level switch was tested with a DC power supply, multi-meter and oscilloscope, with a cup of water. It was tested at first with a stable DC voltage input, to see the output in different levels of water. Then once the output is seen comparable to the input when empty, different DC inputs will be applied to see what the lowest DC input can be without a variation on the output. This was to conserve power, because the sensor constantly has power while the pump is running to make sure the tank has water, because the pump cannot run without a water input. The pump is one of the main power needs, therefor conserving power while it is running is very important, because the moisture sensor will also need some power during that time as well. The testing showed that the sensor should be run at a minimum of 1 volt for a comparable output that will not register as zero.

7.5.3 Irrigation System

The irrigation system was tested for the ideal materials and building methods. The attached pump was connected to the power supply, which was set to the conditions that were found in the pumps test. The pump was in a bucket of water, with tubes attached in a manner that was similar to the final product. The types of tubes were tested, this includes Cross-linked polyethylene pipes, which is used for water piping in houses, and it is a high temperature, high-pressure pipe. Another type of pipe that was tested is flexible PVC tubing or Polyvinyl chloride tubing, it is a low cost tube, with high resistance to other chemicals, and it has a very large variety of applications. Another thing that was tested is the size of the holes for the soaker system and misting system. The test started with needle size holes, and go up or down in size depending on the pressure produced by the pump. After these tests, if the pressure is not acceptable for any of the different tubes or hole sizes, the pump's power conditions will be changed to meet the watering requirements. The results of this testing concluded that PVC tubing had the best flexibility needed for the project, with the right amount of strength. Since it is so flexible, putting holes in the tube was difficult the holes needed to be done with an X-Acto knife because when the holes were punched out they would automatically try to close, therefore the holes had to be a bit bigger than necessary.

7.6 Software Systems

The software components of this project must be verified for correct behavior and quality. The software can be broken up into two main parts, the microcontroller and user interface. Each code piece will be tested individually through unit tests. Once each one has passed the testing procedures, and then they will be integrated together and tested as a whole. An example of this would be when the pH sensor is integrated. The software component for the pH measurements will be first tested with just the pH sensor connected with the microcontroller. After this has passed the test qualifications, the pH sensor will be integrated along with the other sensors once they have been individually tested. Some key testing parameters for the microcontroller section include precision of the sensor

measurements, reliable connections between peripherals, wireless transmission data integrity, and process switching between the command and autonomous modes. The user interface will be thoroughly tested for general graphical user interface (GUI) components, such as ease-of-use, event capturing, and compatibility verification. The software components shall be modified during the testing phase if any do not meet the testing parameters in order to meet all the requirements of the project.

8 Project Operation

The PASS was designed to be simple to use so that there would be minimal user intervention. The user must initiate the system once they have prepared their plant and then the PASS will maintain the plant and only notify the user when something has gone wrong. The following section will cover in more details about the operation of the PASS.

One of the preliminary steps to using the PASS is to place your plant into a 6-inch diameter plastic pot and ensure there is sufficient dirt and fertilizer. Do not worry about watering or taking care of the plant immediately, the PASS will do this after start up. Prior to putting the pot into the system, one must place the red and blue (moisture level and temperature) sensors into the bottom of the pot. Next, carefully slide the pot into the opening on the top of the system until it rests on the stand in the cylinder of the enclosure. Afterwards, the watering tube and pH sensor must be positioned into the soil and clamp the grow light onto the side of the enclosure. The water tank must be filled with enough potable water to allow the water level sensor to signify that the water pump is clear to operate.

The system must be initiated by providing power, which can be done by one of two ways: energy from the battery which is charged via the solar array or alternating current (AC) from the commercial wall outlet. Figure 8-1 shows the sockets available to connect the power sources to the PASS. The keyed socket is the matching pair to the solar tracker which connects to the onboard battery and the IEC-C13 is for the AC wall outlet supply.

Figure 8-1;
Power cord sockets; the above one is for the AC wall connection and the
other forms the connection to the solar tracker

The red switch located on the top of the device controls which power source the system will utilize. This is achieved by turning the switch to 1 or 2, which correspond to selecting the source as the wall outlet or the battery, respectively. Figure 8-2 shows the switch set in the off position, which signifies the PASS is not connected to a power supply. It is suggested to power the PASS primarily with the battery in order to maximize renewable energy use. The option of the AC wall outlet is provided as a backup source or for strictly indoor use of the PASS. The user must be aware that the switch option of 1+2 must not be used for this system, since combining the power sources can create dangerous results. When the system is properly powered, the circuit board located on the top shelf in the electronics compartment will turn on two green LEDs.

Figure 8-2;
Image of the main power switch

At this point, the PASS is prepared to care for the user's plant autonomously. One of the only times that the user needs to intervene with the system is when there is not enough water in the tank. The system defends against running the water pump dry since that can damage the pump. The user can also add supplements to the plant's soil in order to modify the soil pH level. The plant status can be viewed from the user interface mobile application. The water tank can be emptied by using the release valve. The release tube is closed when the valve is perpendicular to the tube and it is open when the valve is parallel to the tube. The image of figure 8-3 shows the release valve in the closed position, which should be maintained while the PASS is in the active mode.

Figure 8-3;
Image of the water tank release valve in the closed position

9 Administrative

Overall management and planning is critical to achieving the objectives of this project. The overview of the PASS organization can be broken down into a few areas including milestone chart, finance and budget controls, member contribution, and future improvements. Each of these topics will be highlighted in their respective sections. Any changes to these items warrant a notification and approval by all team members of this project prior to acceptance. These administration principles were followed and maintained throughout the remaining development of the PASS.

9.1 Milestone chart

The success of this project will rely on careful planning as well as execution of all planned tasks. The milestone charts shown below summarize the proposed work periods on important events that will take place during development of the PASS. The first milestone chart was for the fall semester, going into the winter break. It includes parts of the brainstorming process, research, design, testing, prototyping, and writing. This times when the group comes up with the idea for the PASS, they research and design it. Brainstorm about how the testing and prototyping period, then wrote about it.

Fall 2013 Milestone Chart

The following milestone chart continues from the chart above. It includes design, testing, prototyping, building, and writing.   The design from the previous semester is testing per the document, then redesigned as the testing progresses. Parts were ordered and shipped, and everything was put together for the final presentation.   Pictures were taken during all of these events for the final presentation.

Spring 2013 Milestone Chart

9.2 Finance and Budget Controls

The project finances are a key component that needs to be closely monitored in order for successful completion. Proper part acquisition and flexibility in the design follows from closely observing the planned budget. Table 10.2-1 represents the projected costs including a list of parts with their expected cost from vendors. These parts were chosen based on the overall design requirements of the project along with their price. Table 10.2-2 shows the final expenditures for the project. The list was updated during the prototyping and part procurement processes. The finances were updated and followed as the team continues throughout the prototyping and testing phases to maintain an accurate budget.

Table 9.2-1;			
Projected Budget			
Item	**Quantity**	**Cost / Unit**	**Projected Cost**
Arduino Mega 2560 R3	1	$58.95	$58.95
Vegetronix soil moisture VH400	1	$37.95	$37.95
Vegetronix Soil Temperature Sensor Probe	1	$31.95	$31.95
Ambient Weather WS-2080 Wireless Home Weather Station	1	$129.37	$129.37
70GPH - Statuary Pump w/ 1/4" & 1/2"	2	$13.60	$27.20
100 Watt Solar Panel	2	$149.99	$299.98
Taylor Mini-Greenhouse	1	$38.50	$38.50
Drip Irrigation Kit	1	$12.50	$12.50
SimpleLink Wi-Fi CC3000 BoosterPack	1	$43.99	$43.99
Bulk power cable 12 AWG 25 ft	1	$45.00	$45.00
PWR connectors and receptacles	4	$10.50	$42.00
Plastic Industries Custom Molding Base	1	$248.99	$248.99
Eagle 2 layer PCB	2	$60.00	$50.00
LiterLight LED Grow Lamp	4	$25.00	$100.00
FPFS-P2 Direct-Connect Sump Pump Float Switch	1	$39.95	$39.95
Stepper motor	1	$17.00	$17.00
Sony PAL CX CCD Camera	1	$49.99	$49.99
Wires, resisters, and cap (small signal)	1	$10.00	$10.00
Miler Plastic custom Water tank	1	$135.97	$135.97
SCP1000 Pressure Sensor Module	1	$24.99	$24.99
LFX09L2-BS12 Shorai 12v 9 AH PBEq LiFePO4 Power Sports Battery	1	$105.99	$105.99
INVERTER 150W 12VDC 1OUT	1	$47.00	$47.00
first Prototype build materials	1	$43.85	$43.85
TouchScreen	1	$178.33	$178.33
StarTech FANBOXSL 80mm Case Fan	2	$9.99	$19.98
Arduino pH Sensor	1	$42.00	$42.00
Total			**$1,881.43**

	Table 9.2-2;		
	Bill of Materials and Budget		
Item	**Quantity**	**Cost per Unit**	**Total Cost**
MSP430F5342	4	Free	$0.00
Vegetronix soil moisture VH400	2	$37.95	$75.90
Vegetronix Soil Temperature Sensor Probe	1	$31.95	$31.95
Rn-42 Bluetooth Module	1	$23.04	$23.04
3.8L 12V Mini DC Water pump	2	$19.49	$39.98
30 Watt Solar Panel	1	$131.91	$131.91
pH Sensor	3	$19.98	$59.94
6in Round Pot	3	$2.50	$7.50
Opto-couplers	12	$2.28	$27.44
Bulk power cable 12 AWG 25 ft	1	$45.00	$45.00
PWR connectors and receptacles	4	$10.50	$42.00
Enclosure Plastic Material	1	$128.24	$128.24
Eagle 2 layer PCB	2	$60.00	$107.87
LED Grow Light	1	$26.94	$26.94
Marine-grade Switch	1	$39.95	$39.95
Stepper motor	1	$17.00	$17.00
Enclosure parts	1	$63.38	$63.38
AC Power Cord	1	$13.78	$13.78
PCB components	1	$13.55	$13.55
Bioenno Battery	1	$159.99	$159.99
Bioenno Charge Controller	1	$70.00	$70.00
12V Rectifier	1	$30.84	$30.84
Water level sensors	2	Freebie	$0.00
Apple Developer's License	1	$99.00	$99.00
Extra materials	1	$141.26	$141.26
Total			**$1,396.46**

9.3 Member Contribution

The overall distribution of work on any group project is a critical component to achieving the objectives of the project. A clear and concise plan leads to a better understanding of what each team member is expected to complete as well as showing a clear reflection of the overall status of the project. This works alongside the scheduling and planning phases of the project and it shall be updated in accordance with them. The following section will cover these aspects of the PASS project.
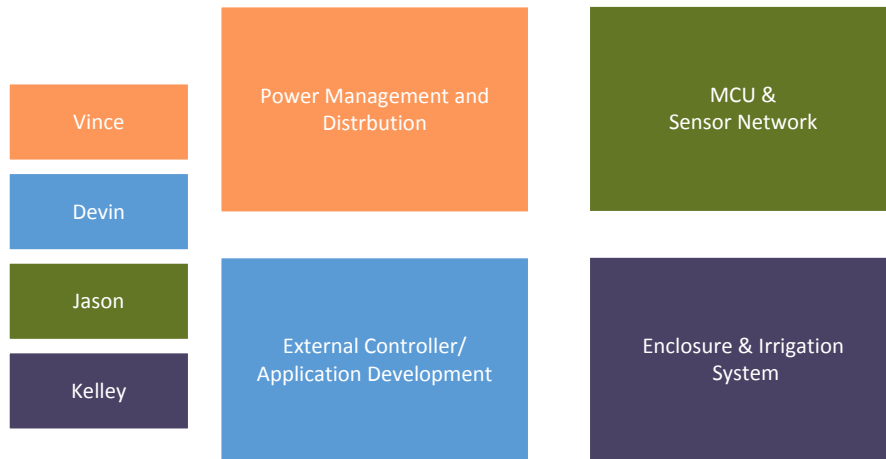
Figure 9.3-1;
Project Work Areas

The work required for this project can be easily broken down into subsections that include the following: power distribution and control, microcontroller system, user interface development, and general enclosure of the system. Figure 8.3-1 shows these areas with an associated group member assigned to each one. Each team member has a work area that they have direct responsibility in regards to decisions, prototyping, and completion of the components that fall in their section.

The project areas was further subdivided according to the type of work referring to either hardware or software development. The power subsystem is referring to the management and design of the batteries, solar cell arrays, and other similar components related to the supply of the energy source of the system. The next system mentioned consists of the components associated with the microcontroller such as the sensor network connections, software development, wireless communications, and data storage. The user interface is the sub-system that is external to the microcontroller and it covers the application software development, wireless communications with the PASS, and as well as the integration with a COTS device that includes as a smart phone or tablet.
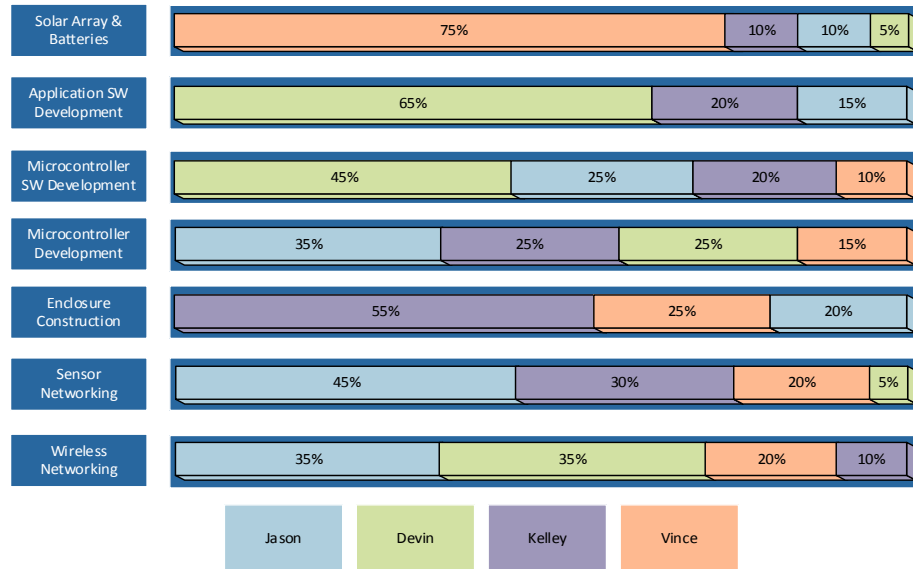
Figure 9.3-2;
Division of Work

The work associated with each of these major work divisions will be spread across the entire team. Figure 8.3-2 shows the separation of work between all the members by dividing the work by percentage. As mentioned before, each section has an individual that will manage it and anyone who is working in that area will follow that person's lead. This style of partitioning work will be maintained throughout the development time of PASS.

9.4 Future Improvements

The allotted time to complete this project is approximately 32 weeks, which limited the amount of work that can be done. The initial design of the PASS directly reflects this observation and these results in exclusion of a few different features that were originally wanted. Table 8.4-1 summarizes the design components that were excluded due to time constraints.

Table 9.4-1a	
Future Improvements	
Feature	**Description**
Accelerometer	This device can allow for detection of when the system tips over and requires user intervention.
Wi-Fi Network	A wireless network via Wi-Fi could be implemented in order to interconnect a series of PASS devices together.
Database	A database with a large array of plant types could assist in the distinction in care treatments for uncommon plants.

Table 9.4-1b	
Fertilization	An automatic fertilization system could add to the autonomous nature of this device and further decrease the amount work needed from the user.
Automatic moving greenhouse	The greenhouse enclosure would be attached to a robotic arm, which would move the greenhouse above the plant if conditions were inappropriate.
Wheels on the system	To be able to move the system around with or without plants, no matter how strong the user would be.
Multiple Moisture Sensors	Use more than one moisture sensor for each plant at different levels. This will let the plant grow from a seed with the correct amount of watering at the different stages of growth.

These omitted features may also be included in future prototypes, if development is continued after submission of the project. Overall, the inclusion of as many features as possible will be a goal for this project, but not all features can be included due to time constraints.

10Appendices
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Al Presher,"Disc Magnet Motors Hit Sweet Spot", DesignNews.com, Aug 2013 Print

III. Abbreviations, Acronyms

A - Amperes
AC- Alternating Current
A/D - analog-to-digital converter
ALU - arithmetic logic unit
API - application programming interface
AWG - American Wire Gauge
BLE - Bluetooth Low Energy
BPS - bits per second
BOM – Bill of Materials
^{o}C - Degrees Celsius
COTS - commercial off the shelf
CPU - central processing unit
CTS - clear-to-send
D/A - digital-to-analog converter
DC- Direct Current
DS-CDMA - direct-sequence code division multiple access
DSSS - direct-sequence spread spectrum
^{o}F - Degrees Fahrenheit
FHSS - frequency hopping spread spectrum
GHz - gigahertz
GPH - Gallons Per Hour
GUI - graphical user interface
Hz - hertz
I/O - input/output
Ins - insufficient
iOS - Apple Mobile Operating System
I^{2}C - inter-integrated circuit
IEEE - Institute of Electrical and Electronics Engineers
IrDA - infrared data association
LAN - local area network
LCD - liquid crystal display
LED - Light Emitting Diode
mAmps or mA - mili-Amps
Mbps - megabits per second
MCU - microcontroller unit
MISO - master in, slave out
Mm - Milimeter
MOSI - master out, slave in
OFDM - orthogonal frequency division
PAR – Photosynthetic Active Radiation
PASS - plant autonomous sustainable system
PC - portable computer
PCB - printed circuit board
P/N - Part Number
RAM - random access memory

RF - Radio Frequency
RISC - reduced instruction set computer
rms - root mean square
ROM - read-only memory
RTC - real time clock
RTS - request-to-send
SCR - Silicon Controller Rectifier
SDK - software development kit
SPI - serial peripheral interface bus
TI - Texas Instruments
UART - universal asynchronous receive/transmit
USB - universal serial bus
USCI - universal serial communications interface
UTC - Coordinated Universal Time
V - Volt
VAC - Volts with Alternating Current
VDC - Volts with Direct Current
VWC - Volumetric Water Content

IV.Wire Gauge Calculation Chart

	Wire Gauge Calculation Chart									
			Maximum Current Draw							
Wire Gauge	**5 Amps**	**10 Amps**	**15 Amps**	**20 Amps**	**25 Amps**	**30 Amps**	**35 Amps**	**40 Amps**	**45 Amps**	**50 Amps**
22 AWG	6 Feet	3 Feet	Insufficient	Insufficient	Insufficient	Insufficient	Insufficient	Insufficient	Insufficient	Insufficient
20 AWG	9.5 Feet	5 Feet	3 Feet	Insufficient	Insufficient	Insufficient	Insufficient	Insufficient	Insufficient	Insufficient
18 AWG	15 Feet	7.5 Feet	5 Feet	4 Feet	3 Feet	Insufficient	Insufficient	Insufficient	Insufficient	Insufficient
16 AWG	24.5 Feet	12 Feet	8 Feet	6 Feet	5 Feet	4 Feet	3.5 Feet	3 Feet	Insufficient	Insufficient
14 AWG	39 Feet	19.5 Feet	13 Feet	9.5 Feet	8 Feet	6.5 Feet	5.5 Feet	5 Feet	4.5 Feet	4 Feet
12 AWG	62 Feet	31 Feet	20.5 Feet	15.5 Feet	12.5 Feet	10.5 Feet	9 Feet	7.5 Feet	7 Feet	6 Feet
10 AWG	98 Feet	49 Feet	32.5 Feet	24.5 Feet	19.5 Feet	16.5 Feet	14 Feet	12.5 Feet	11 Feet	10 Feet
8 AWG	156 Feet	78 Feet	52 Feet	39 Feet	31 Feet	26 Feet	22.5 Feet	19.5 Feet	17.5 Feet	15.5 Feet
6 AWG	248.5 Feet	124 Feet	82.5 Feet	62 Feet	49.5 Feet	41.5 Feet	35.5 Feet	31 Feet	27.5 Feet	25 Feet
4 AWG	395 Feet	197.5 Feet	131 Feet	98.5 Feet	79 Feet	66 Feet	56.5 Feet	49.5 Feet	44 Feet	39.5 Feet
2 AWG	629 Feet	314 Feet	209 Feet	157 Feet	125.5 Feet	104.5 Feet	89.5 Feet	78.5 Feet	69.5 Feet	63 Feet
			Maximum Current Draw							
Wire Gauge	**55 Amps**	**60 Amps**	**65 Amps**	**70 Amps**	**75 Amps**	**80 Amps**	**85 Amps**	**90 Amps**	**95 Amps**	**100 Amps**
22 AWG	Insufficient	Insufficient	Insufficient	Insufficient	Insufficient	Insufficient	Insufficient	Insufficient	Insufficient	Insufficient
20 AWG	Insufficient	Insufficient	Insufficient	Insufficient	Insufficient	Insufficient	Insufficient	Insufficient	Insufficient	Insufficient
18 AWG	Insufficient	Insufficient	Insufficient	Insufficient	Insufficient	Insufficient	Insufficient	Insufficient	Insufficient	Insufficient
16 AWG	Insufficient	Insufficient	Insufficient	Insufficient	Insufficient	Insufficient	Insufficient	Insufficient	Insufficient	Insufficient
14 AWG	3.5 Feet	3 Feet	3 Feet	3 Feet	Insufficient	Insufficient	Insufficient	Insufficient	Insufficient	Insufficient
12 AWG	5.5 Feet	5 Feet	5 Feet	4.5 Feet	4 Feet	4 Feet	3.5 Feet	3.5 Feet	3.5 Feet	3 Feet
10 AWG	9 Feet	8 Feet	7.5 Feet	7 Feet	6.5 Feet	6 Feet	6 Feet	5.5 Feet	5 Feet	5 Feet
8 AWG	14 Feet	13 Feet	12 Feet	11 Feet	10.5 Feet	10 Feet	9 Feet	8.5 Feet	8 Feet	8 Feet
6 AWG	22.5 Feet	20.5 Feet	19 Feet	17.5 Feet	16.5 Feet	15.5 Feet	14.5 Feet	14 Feet	13 Feet	12.5 feet
4 AWG	36 Feet	33 Feet	30.5 Feet	28 Feet	26.5 Feet	24.5 Feet	23 Feet	22 Feet	21 Feet	19.5 Feet
2 AWG	57 Feet	52.5 Feet	48.5 Feet	45 Feet	42 Feet	39 Feet	37 Feet	35 Feet	33 Feet	31.5 Feet

Use this chart as described below, determine the proper AWG (gauge) rating for the main power and ground wires. Be sure to size both wires to this gauge.

1) Determine your maximum current draw

2) Find the column that matches your current draw

3) Within that column, find the row that best represents the distance a length of wire will travel to connect to the battery.

4) The heading for this row indicates the minimum size AWG (gauge) your power and ground wires will be in order to safely carry your current draw.

V. Microcontroller Schematic