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SENIOR DESIGN I

Final Document

"Automated Rotating Solar Plant Rack with Self Irrigation System and Moisture Level Sensors"

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1.0 Executive Summary

Horticulture has been at the root of our civilization since the early days of mankind. Since the beginning, plants have been a necessity from providing nutritional food that gives us energy to being used as shelter to keep us safe and warm. As time has progressed, they have been used to create an agricultural economy, providing a source of income as well as food for those around the world. In more recent years, plants have been harvested to create medicine to extend the lives of those suffering as well as to create a more lively living space for those cooped up in a small apartment. Although the usage of plants has been evolving for centuries, the method for growing them has remained relatively constant.

It is well known that plants require water and sunlight. With that, they can perform photosynthesis and produce the nutrients required to survive. However, these living organisms cannot move around on their own and therefore, must receive their supplements from an outside source. Some plants grow outdoors. These are lucky enough to receive a constant stream of sunlight for most hours of the day as well as water whenever it rains. If they require more than the environment can provide, their seeds will be carried to a new location by bugs, animals, or wind where they can grow into a new, better-suited plant. This is the ideal situation as the plant is able to get everything that it needs to live.

Other plants are grown indoors. These are typically flowers are small vine-like plants that provide a little pop of color to a home. These plants also require sunlight and water but don't have the luxury of nature to provide it for them. Instead, they must seek another source for their care. Generally, this responsibility falls to the humans. We are the ones that must provide all nutrients to the plant in order to assure its survival. In order to provide sunlight, the plant must be placed in a sunny spot or have an artificial source that will shine the same nutrients on the plant. Water must also be provided to the plant in regular intervals. The timing and amount of water varies depending on the type of plant provided.

Although this task appears to be rather straight forward, it is a large commitment and can be challenging for some growers. While some are blessed with a laidback schedule, others are not. These people have incredibly busy schedules with little to no free time. They are the ones who have so much on their plate that the mundane task of watering a plant can easily be forgotten. Some of them do remember to water but are not able to as they spend long periods of time away from their home. Others simply will go on vacation for a longer period in which they will not have the ability to water their plant. In these situations, the plant unfortunately will suffer and with time, will ultimately lead to its demise.

With the current state of our world and the ever-growing importance of business, it is likely that the situations described above will continue to be problematic. People will continuously have busy schedules and be away from their plants long enough to cause issues. For this reason, a solution must be found. The only uniformly accepted solution is to ask another person, like family or a neighbor, to take care of the plant while one is away. This is a great technique but cannot be adopted by all. Not everyone has a trustworthy companion who is competent enough to handle such a task. That being said, there must be other ways of assuring care for the plant. That is where this project comes into play.

This project aims to address the problem of leaving plants unattended for too long. It does so by creating a system that will monitor the conditions of the plant and assure that it is receiving the appropriate amounts of water and light. This will allow the plant to be left alone for periods of time and still receive the care that it requires

To start, there will be an irrigation system. This will be responsible for providing water to the plant. The system will consist of water pumps placed within the pot as well as a giant bottle to hold the liquid. When a signal is received, the system will send water from the bottle to the pumps where it will then be expelled into the soil around the plant. This will continue until a second signal has been received telling it to stop. The timing will be entirely under the control of timers within the microcontroller. The irrigation system is the only system that will provide the all-important water for the plant.

The second system is the rotational system. Its purpose is to rotate the plant on an axis to assure that it receives equal sunlight on all sides. This was put into place to assure that the plant will grow straight up rather than at an angle. Plants will always grow towards the Sun. If the sunlight is only coming from one direction, like it does on a windowsill, the plant will follow accordingly. This is not ideal as the bent over plant is not nearly as appealing as one that grows up. This is the responsibility of the rotational system. Using a plant and a small motor, the plant will be rotated on an axis several times a day to assure even sunlight on all sides. Using light sensors and timers, it will time the amount the sunlight received on each side and use that to calculate when it is time to rotate. This system will allow for plants that grow perfectly straight with no hint of bending in its stem.

The last system is the shading system. This is used to protect the plant from the scorching rays of the Sun. Some environments receive a tremendous amount of sunlight on a daily basis. While some plants thrive with more exposure, others do not. The shading system takes that into consideration. When the sensors detect that the plant has reached its maximum threshold of sunlight, it will spring into action. The shading system will consist of a metal pole with a device on the end that is similar to an umbrella and a folding fan. After receiving the signal, the umbrella will unfold and provide shade and protection for the plant. It will remain this way until the system decides that the plant can receive more light. At that time, the device will refold, allowing the plant to receive sunlight once again. This system was intended to protect the more delicate plants from receiving too much light and ultimately drying up.

As stated above, the purpose of this project is to solve the problem of plant malnutrition due to lack of care. With the help of the irrigation, rotational, and shading systems, this problem will be solved. The irrigation system will provide the plant with water while the shading and rotational systems will provide the required sunlight in equal and appropriate amounts. When all three systems are working together, the plant will receive all required nutrition without the assistance of a human caretaker. Using the mobile application, the plant owner can set a maintenance schedule or select a preset schedule for a certain plant type. The microcontroller would receive this communication and activate the sensors and mechanical systems to carry out this schedule. This provides an exceptional solution to the problem at hand.

2.0 Project Description

In this section different existing projects and/or products will be discussed to be compared with the proposed design of this project. In addition, the motivation and goals of this project will be described in this section. Also, the engineering requirements specification, marketing and engineering requirements, and the House of Quality and block diagram of the project will be discussed and presented in this section.

2.1 Existing Projects and Products

In the market, there are different existing products that have similar characteristics as that of the proposed design of this project. However, they differ in some way since there is no product with all the proposed features and characteristics. In this section, different existing products are presented to be compared with the proposed design. Here, different products with sensors, irrigation system, rotation system, and shading system are discussed.

2.1.1 Plant Pot with Sensor and Irrigation System

Parrot Pot is an existing plant pot which consists of multiple sensors and an automatic watering system. It has four embedded sensors to take accurate, real-time measurements of data that is vital for the plant's health. Among these sensors are sunlight, fertilizer level, temperature, and soil moisture sensors. The automatic watering system provides the right amount of water at the right time which encourages the plant's growth. In addition, Parrot Pot optimizes water consumption by providing up to one month of unattended automatic watering.

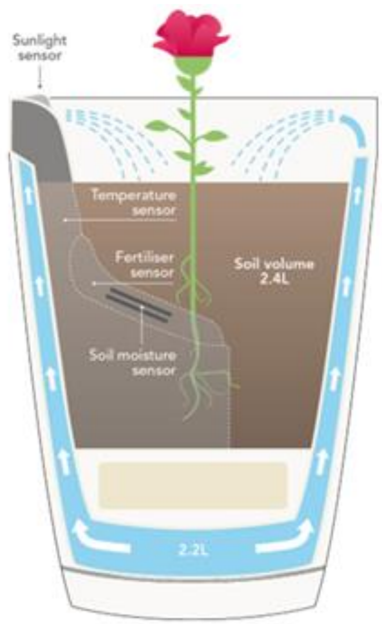


Figure 1: Existing Plant Pot with Sensors and Automatic Watering System *(Source: Parrot Pot)*

This plant pot is made of plastic and comes in a variety of colors. Its dimensions are 8.09 x 8.09 x 12.28 inches (LxWxH), and its weight is 3.31 pounds. Parrot Pot requires four AA batteries to power the system.

By comparing this design with the proposed one, it can be observed that both have similar features. Even though Parrot Pot comes with an additional fertilizer level sensor, it does not have a shading system or a rotational system as the proposed design. In addition, it is powered by four AA batteries, while the proposed design will count with a solar power system.

There are other plant pots in the market that share similar features with the Parrot Pot. However, none of them have all the features proposed in a single system. Also, most of these products are designed for indoor plants.

2.1.2 Plant Pot with Rotation System

After researching different plant pots with an electrical rotation system, none of the plant pots in the market include this feature. However, there are existing plant stands with wheels integrated to be rotated manually. However, these stands do not compare to the proposed design since the plant stand to be designed will have an electrical rotational system which will work based on the light sensor collected data. GeBot requires human interaction to perform this task, while the purpose of this project is to reduce the human interaction when growing a plant.

Figure 2: Existing Manual Rotating System *(Source: GeBot)*

Figure 3: Existing Electric Motorized Rotating Turntable Stand *(Source: Homend)*

On the other hand, there are existing motorized turntables stands in the market. However, these are commonly used to display products, jewelry, among others. They are not intended to be used as plant stands. Although they can possibly be used to place a plant pot, they will be a separate system which will not be controlled by a light sensor.

The proposed feature of the integrated motorized rotation system in the plant rack is an important feature that ensures equal amount of sunlight in the entire plant through the data collected from a light sensor. This feature reduces human interaction in the care of a plant.

2.1.3 Plant Pot with Shading System

Vegepod Raised Garden Bed is a container gardening with different features. This elevated bed design protects soil, stops trees pilfering nutrients, retains warmth, stops contamination, controls nutrient levels, is portable, and easy to maintain and fill. This product includes a self-watering system and mist spray irrigator. Its design includes a shading system consisting of a commercial grade canopy. However, it is a manual system that must be operated by human interaction. Even though this canopy stops all pests, weather, and weeds, it is not automated and is not controlled by sensors data.

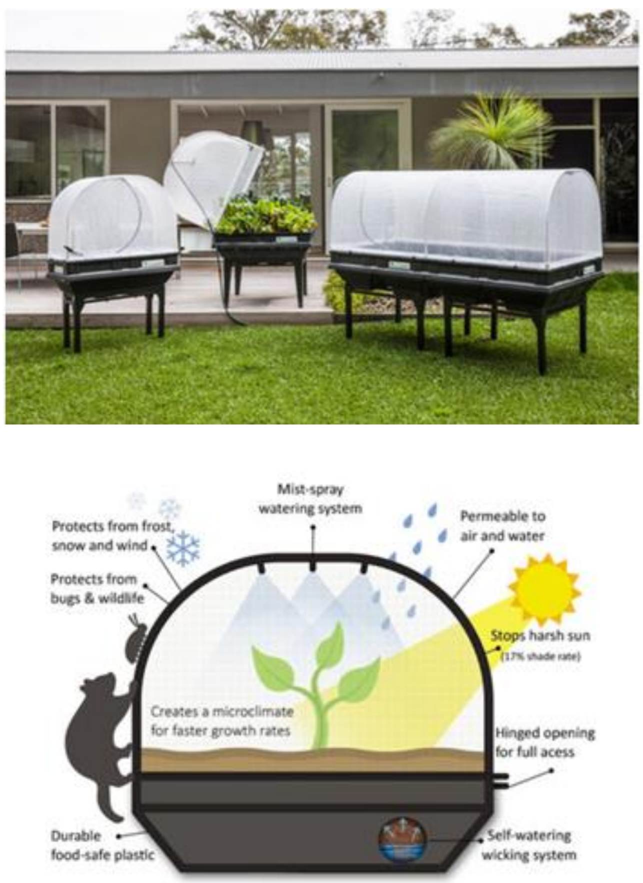


Figure 4: Existing Shading Systems for Plant Pots *(Source: Vegepod)*

2.2 Motivation

The motivation of this project is based on different factors. This project idea arises from a personal experience faced during daily living. Almost in every home, people have at least one plant that requires a specific treatment in order to grow healthy. Many people do care about their plants' health. However, not all the time, they have the required amount of time to provide the right care for a plant or multiple plants. So, this project aims to address this issue by creating a system that takes care of these plants without much human interaction. This will reduce the human dependency of the plant to fulfill its basic needs. The system will keep track of the temperature, soil moisture, and light exposure through the use of multiple sensors to ensure the plant is living under good conditions. These sensors will provide quantitative information which will determine if some mechanical systems such as a rotational system, a shading system, or an irrigation system need to operate. The rotational system will rotate the plant after some time of exposure to the sun to assure all sides of the plant obtain the same light. The shading system will cover the plant if it is receiving more light than required. The irrigation system will provide the needed water to assure the plant is well hydrated. With these sensors and mechanisms some of the basic needs of a plant will be covered without human interaction which address most of the people's concerns about a plant's health.

In addition, this project is motivated to demonstrate the knowledge gained through the academic path. Each member has a specific strength in the electrical engineering field which contributes to different aspects of the design, implementation, and creation of this project. Also, the teamwork is reinforced in this project, which introduces each member to similar career environments faced in the electrical engineering industry. A final but not least important motivation is to complete a degree at the University of Central Florida with vast knowledge and experience to affront the real world demands on the selected career paths.

2.3 Goal

This project will be designed using multiple sensors as inputs to monitor the current state of the plant. The device will monitor the moisture in the soil using a moisture sensor. If it determines that the plant is too dry, it will use an irrigation system to provide it with water. The device will also be equipped with temperature and light sensors that will monitor the sun explode for the day. If the plant has spent too much time in the sun, an umbrella-like structure will be used to provide shade. Finally, a rotational system will be added to rotate the plant as needed. Generally, any form of plant will grow towards the sun so it gets maximum exposure. However, this is not ideal for some as the plant may look lopsided. To prevent this from occurring, it will be placed on top of a rotational system. This will assure that the plant gets equal exposure on all sides and will grow straight up.

This device can be used in many ways. For example, having a device that will take care of plants will be incredibly beneficial to those with houseplants. When a family decides to go on vacation, their plants can suffer as there will be no one around to water them. An automated system can assure that the plant receives all of the care that it requires while the family is away. This system can also be beneficial to those with busy schedules.

Having a device that will always remember to water your plants will take one thing off of the person's schedule.

2.4 Engineering Requirements Specifications

In this section, different engineering requirements specifications will be discussed based on each subsystem of the proposed design. Each subsystem will need to meet specific targets and have particular features for the project to successfully operate.

Section	Description	Requirement
Power System	• Must be capable of powering multiple sensors and mechanical systems, and a controller • Must have current leakage protection	Output Power > 20W Efficiency >70%
Battery	• Must be able to supply power to all the component on the system • Must be able to charge via solar panels	Capacity > 10Ah Charging Time < 4 hours
Solar Charge Controller	• Must have overcharge protection to limit current when fully charged battery	Output Voltage 12.6V – 13.7V (when receiving light)
Voltage Regulator 1	• Must be able to regulate varying input voltages to 5V	Output Voltage Tolerance ±2mV
Voltage Regulator 2	• Must be able to regulate varying input voltages to 3.3V	Output Voltage Tolerance ±2mV
Irrigation System	• Must automatically turn on once moisture level falls below application set value and turn off once level is acceptable again	Output Rate 0.2 Liters/Minute
Light Sensor	• Must communicate to the microcontroller's ADC input	Detection > 10000 lux
Moisture Sensor	• Must be able to calibrate to a certain plant's soil and output to fit a range of 1024 bits • Must be resistant to corrosion due to moisture	Delay cycle > 1 second
Shading System	• Must be able to take an input from the application, and electrically open and close to shade the plant	Deploys in < 1 minute

Section	Description	Requirement
WiFi Module	● Must connect to the Internet following the 802.11 protocol and WPA2 security settings	Minimum Speed: 2.4 GHz
Microcontroller	● Must successfully communicate with the other components via UART/SPI ● Must be able to interpret data from the sensors ● Must be able to analyze sensor data and respond accordingly via the output devices ● Must be able to communicate with the application via 802.11 protocol ● Must successfully implement multiple clocks silmultaneously	Power Consumption < 50mA Operating Voltage 5V
Application	● Must be able to successfully send inputs to the microcontroller via WiFi ● Must be able to adjust plant time spent in sun ● Must be able to adjust moisture level of plant ● Must be compatible with Android devices ● Must have a reasonable file size	Installation Time < 5 minutes File Size < 20MB
Product Installation Time	● Must be easy to physically install	Install Time < 10 minutes
Cost	● Must be affordable	Cost < $200
Dimensions	● Must be large enough to hold an average sized house plant ● Must be small enough to be lifted by an average sized person	Dimensions < 36''H x 14" D

Table 1: List of Requirement Specifications

2.5 Marketing and Engineering Requirements

In this section, different marketing and engineering requirements will be discussed in the House of Quality to compare each requirement. The ratings in the center represent the correlation between the marketing requirements and the engineering requirements. The marketing requirements are given to the left of the ratings while the engineering requirements are given above the ratings. The roof, or correlation matrix, correlates the engineering requirements among each other. Finally, the final row shows the benchmark each engineering requirement must fulfill for a successful design.

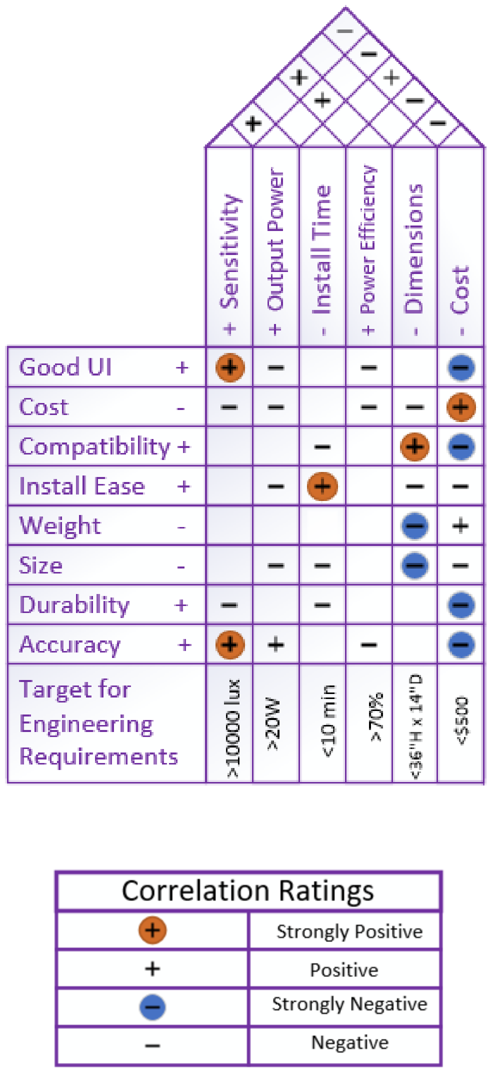


Figure 5: House of Quality Diagram

2.6 Block Diagram

In this section, a block diagram of the proposed design is presented. Here, the role of each member is described based on the coloring of each block. Christina Quinones oversees designing and implementing the power system, solar panel, and battery. Melissa Rose designs and implements different sensors as the light sensor, temperature sensor, moisture sensor, and Wi-Fi module. Abigail Michael designs and implements the controller or board of the system and the software development of the application. Brian Geibig designs and implements the electromechanical subsystems such as rotation, shading, and irrigation systems.

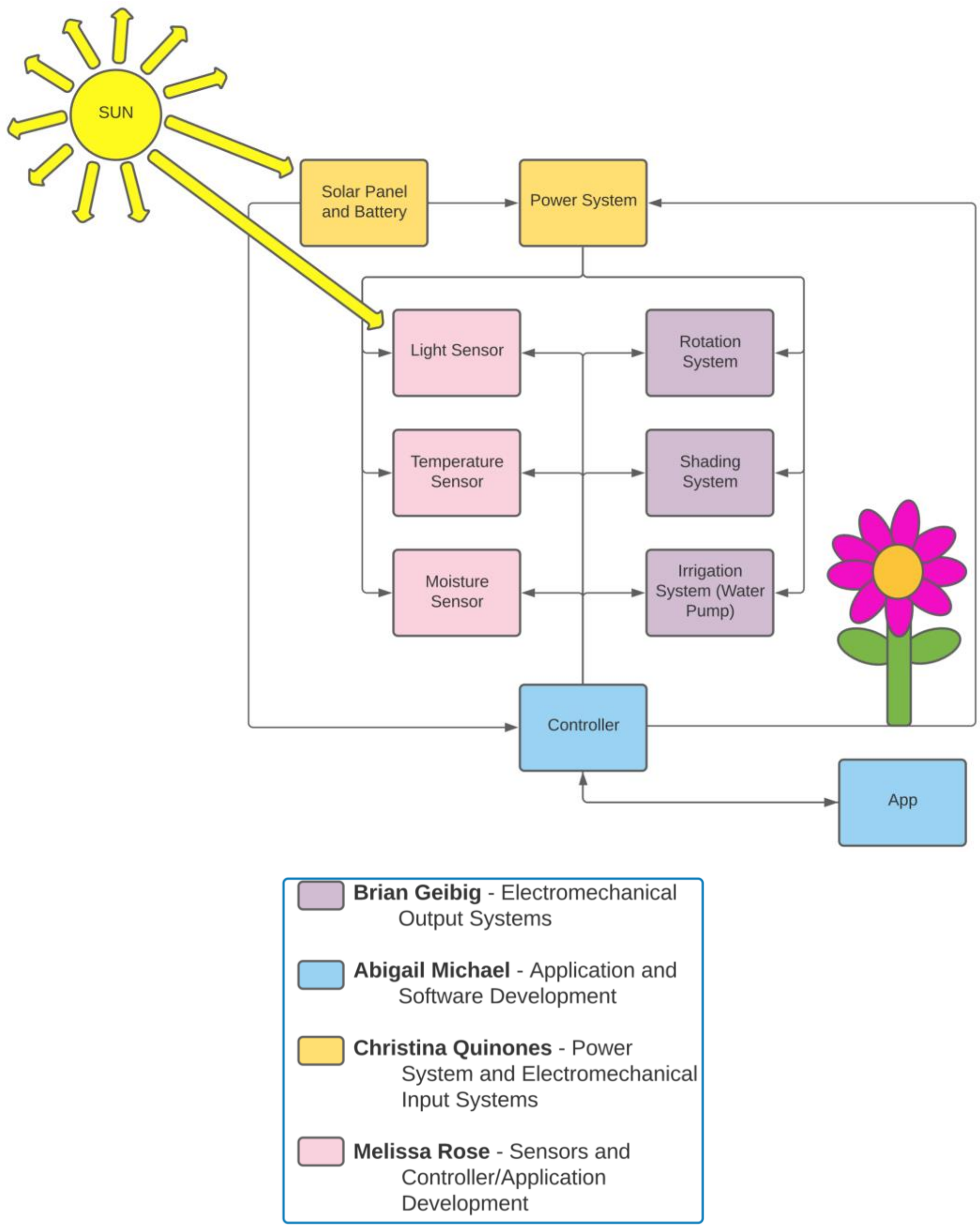


Figure 6: Project Block Diagram

3.0 Research

In this section, different relevant technologies to be included in the proposed design are discussed. In addition, different components will be studied to select the best elements to be included in the final design. Based on the part selections, a possible design will be presented through different diagrams and schematics.

3.1 Relevant Technologies

Different relevant technologies to be included in the proposed design will be studied to select the best fits for the final project design. The technologies to be discussed are: photovoltaic cells, voltage regulators, charge controllers, rechargeable batteries, light sensors, temperature sensors, soil moisture sensors, Wi-Fi modules, microcontrollers, application design software, and motors.

3.1.1 Photovoltaic Cells

Solar panels are composed of a grid of photovoltaic cells or solar cells protected with a backsheet and covered with glass on the front. These cells are made from silicon, which is a semiconductive material, with electrical contact plates on the face. Due to the silicon conductivity properties, the cells produce an electric current if they are exposed to light and are therefore a type of optoelectronic device. This process recalls the photoelectric effect which consists in absorbing photons of light and releasing free electrons that result in an electric current when captured. This electric current can be then used as electricity to power a load.

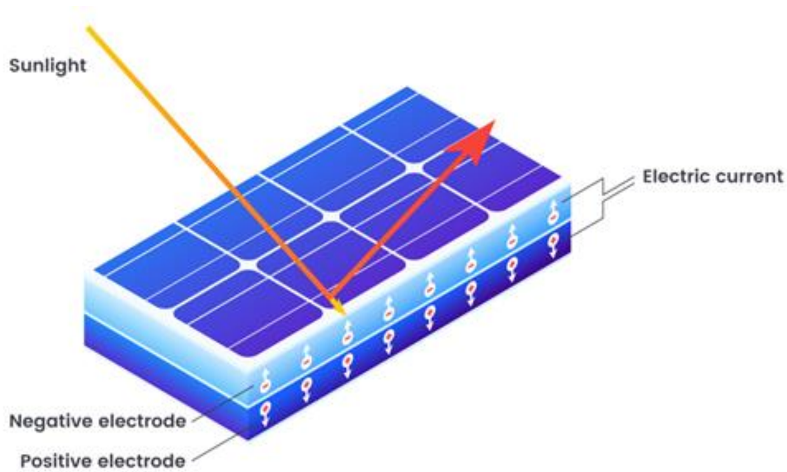


Figure 7: Photovoltaic Cell

The use of photovoltaic cells in solar panels represent an excellent source of power for the project design. Since this project aims to reduce the human interaction to care for a plant, this power source is advantageous since it requires low to no maintenance. They just need to be relatively clean, which can be done a couple of times per year. In addition, this is a renewable source which means it is not depleted after harvesting the sun's rays for energy many times. Also, the use of solar panels in the design will represent a no cost in the electric bill to the consumer since the system will be off grid designed.

Nowadays, photovoltaic energy is used in many different fields such as transportation, wearables, lighting, heating, electricity, and ventilation. Despite the application to be performed, the main goal of solar panels is to generate energy with the use of sunlight. This characterizes a key feature for the design of an autonomous system to take care of a plant.

3.1.2 Voltage Regulator

Most electronics are designed to operate at a certain voltage range, some of them requiring a constant voltage level. To generate this constant voltage, a voltage regulator is implemented in the electronic circuit design. This voltage regulator maintains a constant voltage regardless of the variations in the input voltage or loading conditions. The voltage regulator is placed between the power supply and the device requiring a constant voltage to regulate the incoming input voltage into a lower or higher and stable output voltage. These devices can regulate both AC and DC voltages. Voltage regulators are used in different applications such as power supplies to electronic devices, alternators of internal combustion engines, and electronics circuits. Despite the application, the implementation of a voltage regulator has the main goal of regulating the output voltage or the alternator output to supply a precise voltage and save the devices from any damage.

3.1.2.1 Linear Voltage Regulator

Figure 8 shows the general architecture of a linear voltage regulator. Linear voltage regulators are devices based on the use of a transistor (BJT or MOSFET) controlled by a negative feedback high gain differential amplifier. The negative feedback loop maintains a stable output voltage despite the input voltage and load current variations by comparing the output voltage with a precise reference voltage. A voltage-controlled current source is used to force a constant and stable voltage to appear at the output terminal of the device. These devices are step-down converters, so the input voltage will be higher than the output voltage. *(TI - SNVA558)*

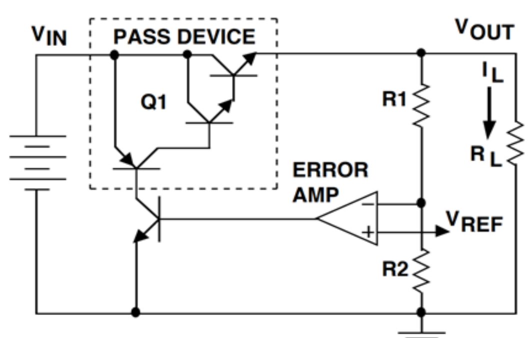


Figure 8: General Linear Voltage Regulator Schematic *(Source: Texas Instruments - Literature SNVA558)(Permission Requested)*

As many electronic devices, linear voltage regulators have their advantages and their downsides depending on the application to be implemented. These devices are simple, have a low cost, respond quickly to changes at the input and the load, and have no switching noise. However, their bigger downside is their low efficiency in some applications. The pass transistor dissipates power which can cause the regulator to get warm and lower its efficiency. *(TI - SNVA558)*

There are many different types of linear regulator of which three basic types will be studied: Standard (NPN Darlington) Regulator, Low Dropout or LDO Regulator, and Quasi LDO Regulator. These three types differ primarily by their dropout voltage, which is the minimum voltage drop required across the regulator to sustain output voltage regulator, and by the ground pin current. *(TI - SNVA558)*

3.1.2.1.1 Standard (NPN Darlington) Regulator

Figure 9 shows the circuit schematic for the Standard (NPN Darlington) Regulator. This device uses the NPN Darlington configuration to model the pass device. One of the most important aspects that needs to be considered is the minimum voltage required across the pass transistor to maintain output regulation. This voltage is determined to be: *(TI - SNVA558)*

$$V_{D(MIN)} = 2V_{BE} + V_{CE}$$

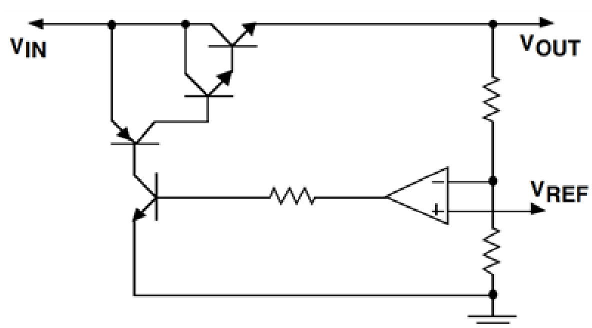


Figure 9: Standard (NPN Darlington) Regulator *(Source: Texas Instruments - Literature SNVA558)(Permission Requested)*

The minimum voltage required is about 2.5V to 3V, which is set by the manufacturer. This requirement allows for the -55oC to +150oC to assure performance specification limits. For this device, the dropout voltage is around 1.5V and 2.2V, which depends on load current and temperature. *(TI - SNVA558)*

On the other hand, the ground pin current is very low since the base drive current to the pass transistor equals the load current divided by the gain of the pass device. The pass transistor of this regulator implements one PNP and two NPN transistors. This design causes the total current gain to be very high which contributes to a very low ground pin current. *(TI - SNVA558)*

3.1.2.1.2 Low Dropout or LDO Regulator

Figure 10 shows the circuit schematic for the Low Dropout (LDO) Regulator. This device uses a single PNP transistor to model the pass device. As stated before, one of the most important aspects that needs to be considered in the voltage regulator design is the minimum voltage required across the pass transistor to maintain output regulation. This voltage is determined to be: *(TI - SNVA558)*

$$V_{D(MIN)} = V_{CE}$$

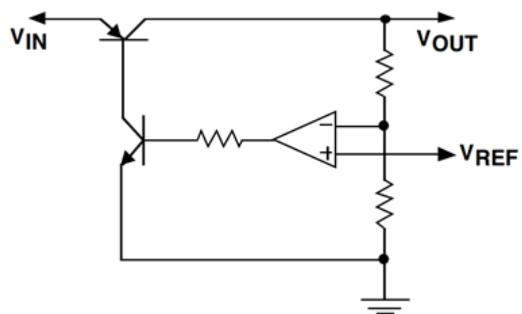


Figure 10: Low Dropout (LDO) Regulator *(Source: Texas Instruments - Literature SNVA558)(Permission Requested)*

This minimum voltage is the voltage across the PNP transistor in the pass device. The maximum specified dropout voltage of this device is about 0.7V to 0.8V, typically around 0.6V. The dropout voltage relates directly to the load current, meaning that the lower the load current, the lower the dropout voltage. This characteristic makes the LDO regulators to be most used in applications where the power is provided by a battery. LDO regulators provide high efficiency and maximally use the available input voltage. *(TI - SNVA558)* On the other hand, the ground pin current of this regulator approximates to the load current divided by the gain of the single PNP transistor.

3.1.2.1.3 Quasi LDO Regulator

Figure 11 shows the circuit schematic for the Quasi Low-Dropout Regulator or Quasi-LDO Regulator. This device uses both an NPN and a PNP transistor to model the pass device. It is a variation of the Standard regulator with the integration of the LDO regulator, both designs are described above. As stated before for both the Standard and LDO regulators, one of the most important aspects that needs to be considered in the voltage regulator design is the minimum voltage required across the pass transistor to maintain output regulation. This voltage is determined to be: *(TI - SNVA558)*

$$V_{D(MIN)} = V_{BE} + V_{CE}$$

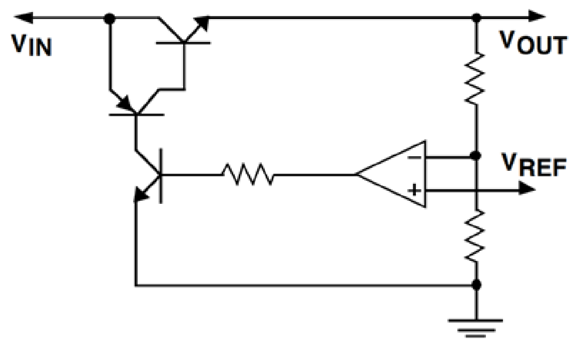


Figure 11: Quasi Low-Dropout Regulator *(Source: Texas Instruments - Literature SNVA558)(Permission Requested)*

The dropout voltage of this device is about 1.5V(max) at rated current. This voltage depends on both the temperature and the load current and cannot go below 0.9V at 25^{o}C. On the other hand, the ground pin current is very low as that of the Standard regulator. *(TI - SNVA558)*

3.1.2.2 Switching Voltage Regulator

Figure 12 shows a general design for a switching voltage regulator. Switching voltage regulators use switching semiconductor devices, like transistors, to transform the input power into a pulsed voltage. This pulsed voltage is smoothed by using storage elements as capacitors and inductors, and other elements. This device works by turning ON the switch to supply the power from the input terminal to the output terminal. When the desired voltage is achieved, the switch is turned OFF which prevents input power consumption. This process provides high power efficiency as well as design flexibilities by allowing the generation of multiple output voltages from a single input voltage.

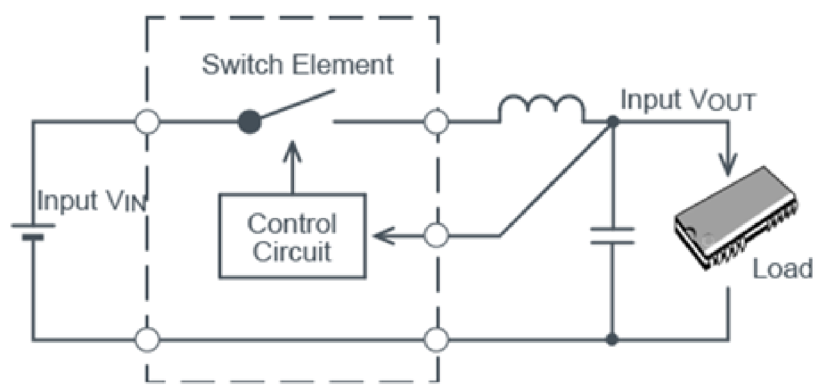


Figure 12: General Switching Voltage Regulator Schematic *(Source: Rohm Semiconductor)(Permission Requested)*

The output voltage regulation of these devices is based on Pulse Width Modulation (PWM). This means that the feedback loop will regulate the output voltage by changing the ON time of the switch (transistor) component. These devices have small energy losses which result in a range of 80% to 90% efficiency and a typical efficiency around 85%.

There are different types of switching regulators which achieve different DC output voltage levels based on a given DC input voltage. However, for the project design purposes, only the Buck and Boost regulators will be studied.

3.1.2.2.1 Buck Regulator

Figure 13 shows the circuit schematic for a buck regulator. The buck regulator, also known as the step-down regulator, takes a certain DC input voltage and converts it into a lower DC voltage of the same polarity. The switching component of this device is modeled with a transistor to alternatively connect and disconnect the input voltage terminal to a memory element, an inductor. *(TI - SNVA559)*

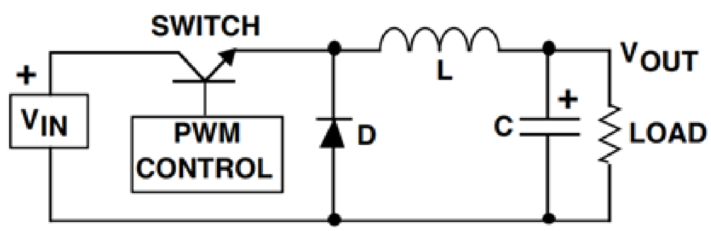


Figure 13: Buck Regulator *(Source: Texas Instruments - Literature SNVA559)(Permission Requested)*

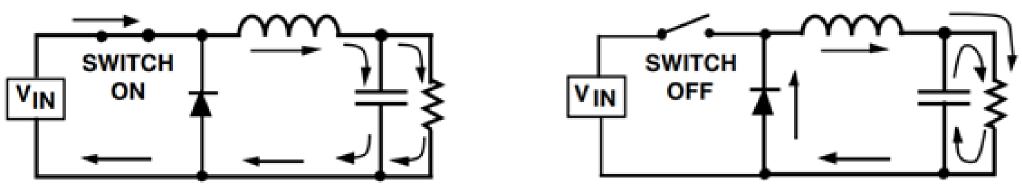


Figure 14: Buck Regulator Switching Current Flow Paths *(Source: Texas Instruments - Literature SNVA559)(Permission Requested)*

Figure 14 shows the different paths the current flow takes based on the switching process. From the image to the left, it can be observed that the input voltage terminal is connected to the inductor when the switch is turned on. Here, the existing difference between the input and output voltages is forced across the inductor which produces a higher inductor current that is distributed between both the load and the output capacitor. In this process, the capacitor, another storage and memory element, charges. From the image to the right, it can be observed that the input voltage terminal is no longer connected to the inductor. However, it is well known that the inductor current cannot change instantaneously so that the inductor voltage will adjust to maintain a constant current. When the current decreases, the input of the inductor takes a negative voltage which at a certain point causes the diode, another semiconductor device to turn on. This causes the inductor current to flow through the load and then back to the diode. In this process, the capacitor discharges into the load, which causes the flow of the entire inductor current through the load. *(TI - SNVA559)*

3.1.2.2.2 Boost Regulator

Figure 15 shows the circuit schematic for a boost regulator. The boost regulator, also known as the step-up regulator, takes a certain DC input voltage and converts it into a higher DC voltage of the same polarity. The switching component of this device is modeled with a transistor to alternatively connect and disconnect the output end of the inductor to the diode which is in charge of transferring the inductor current to the capacitor and the load when forward biased. *(TI - SNVA559)*

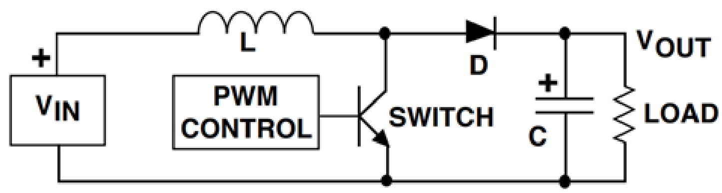


Figure 15: Boost Regulator *(Source: Texas Instruments - Literature SNVA559)(Permission Requested)*

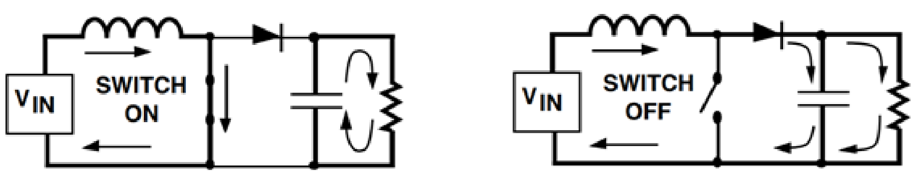


Figure 16: Boost Regulator Switching Current Flow Paths *(Source: Texas Instruments - Literature SNVA559)(Permission Requested)*

Figure 16 shows the different current paths taken based on the switch position. It can be observed that when the switch is on, the input voltage is forced across the inductor. This causes the inductor current to increase which causes a small voltage at the output end of the inductor not sufficiently high to turn on the diode. In this case, the capacitor is in charge of supplying all the load current. On the other hand, when the switch is off, the inductor current decreases and its output end produces a positive voltage, which forward biased the diode. Once the diode is forward biased, the capacitor is able to charge at a higher voltage compared to the input voltage since the inductor current flows through the diode and is being distributed between the capacitor and the load. *(TI - SNVA559)*

3.1.3 Charge Controller

Charge controllers are devices installed between the energy source, in this case a solar panel, and the storage, which corresponds to the battery bank. These devices have a semiconductor to control the charge current passing through it. Charge controllers prevent batteries from overcharging when a certain voltage is achieved by reducing the flow of energy to the battery. These devices provide different important functions for power systems such as overload protection, low voltage disconnects, and block reverse currents.

The overload protection oversees the current flowing into the batteries. This prevents high currents from flowing into the battery bank which can cause overheating and fires. The low voltage disconnect is a mechanism that disconnects non-critical load if the voltage is lower than a predetermined threshold. These non-critical loads reconnect once the battery is being charged. This action prevents the system from over-discharging and operating at severely low voltages. In addition, these devices block reverse currents. Photovoltaic cells current flow through the batteries in one direction. However, when the sun is not present, photovoltaic cells may inherently pass some current in the opposite direction. Charge controllers prevent these reverse currents from flowing to avoid battery discharge.

3.1.4 Rechargeable Batteries

Rechargeable batteries perform reversible chemical reactions to allow the energy or charge to be stored once the battery is drained. One or more electrochemical cells contained within these electrical batteries are responsible for these reverse chemical reactions allowing the battery to store energy every time it is drained. The construction of these batteries follows a similar design as that of regular batteries. They consist of an anode, a cathode, and an electrolyte. In the charging process, the anode produces electrons while it is oxidized, and the cathode consumes electrons while being reduced. As well known, the current flow outside the circuit is due to the electrons flow or movement. On the other hand, the electrolyte controls the internal flow of the electrodes by acting like a buffer. The electrolyte can be lithium-ion and nickel-cadmium cells, or lead-acid cells which are active contributors in the electrochemical reactions.

There are different types of rechargeable batteries including lead-acid, nickel-cadmium (NiCd), nickel-metal hydride (NiMH), lithium-ion (Li-ion), lithium-ion polymer (LiPo), and rechargeable alkaline batteries. These types will be described below to select the best fit for the project design.

3.1.4.1 Lead-Acid Batteries

Lead-acid batteries are ones of the first invented types of rechargeable batteries. They supply high-surge current allowing the cells to maintain a large power-to-weight ratio.

3.1.4.2 Nickel-Cadmium Batteries (NiCd)

Nickel-cadmium batteries use nickel oxyhydroxide (NiOOH) positive electrodes, and the negative electrodes use a cadmium-absorbing alloy. These batteries have less capacity than a nickel-metal hydride battery.

3.1.4.3 Nickel-Metal Hydride Batteries (NiMH)

Nickel-metal hydride batteries are similar to nickel-cadmium batteries since they use nickel oxyhydroxide positive electrodes as well. However, the negative electrodes use a hydrogen-absorbing alloy. These batteries have more capacity than nickel-cadmium batteries being that they are two to three times bigger. Also, the energy density of these batteries approaches that of lithium-ion batteries.

3.1.4.4 Lithium-Ion Batteries (Li-ion)

Lithium-ion batteries recharge through the movement of lithium ions from the negative electrode and positive electrode. When the battery is discharging, these ions move from the negative electrode to the positive electrode. When the battery is charging, the movement is reversed. In this case, the ions move from the positive electrode to the negative electrode. Conventional lithium-ion batteries are composed of a positive electrode made from a metal oxide, a negative electrode made from carbon, and an electrolyte made from a lithium salt in an organic solvent.

3.1.4.5 Lithium-Ion Polymer Batteries (LiPo)

Lithium-ion polymer batteries consist of numerous secondary cells in parallel. This configuration the discharge-current capability to increase. Although they are composed of lithium ions, the major difference between lithium-ion polymer batteries and regular lithium-ion batteries is that the electrolyte made of lithium salt is not an organic solvent. The lithium salt electrolyte, in this case, is made of a solid polymer composite which can be a polyethylene oxide or a polyacrylonitrile.

3.1.4.6 Alkaline Batteries (RAM)

Alkaline batteries depend on the reaction between zinc (Zn) and manganese dioxide (MnO_2). These batteries come fully charged from manufacturing and compared to nickel-cadmium and nickel-metal hydride batteries, they carry their charge for a longer period.

3.1.5 Light Sensor

A light sensor, or photocell, is an optoelectronic device that detects electromagnetic radiation. Light-detecting devices include photoresistors, passive components that change their resistance based on the presence and intensity of light, and phototransistors and photodiodes, active components that change their current (or rate of electron flow) based on light intensity. Light sensors can be designed to detect certain frequency bands within the spectrum, such as infrared, visible, and ultraviolet (Spiess). In general, a light sensor works by transforming photons, packets of light or EM radiation, into electrical signals.

3.1.5.1 Photoresistors

Photoresistors, also referred to as LDRs (light dependent resistors) consist of a ceramic substrate with the zagged, resistive path typically made out of cadmium sulfide (CdS), because according to Electronics Tutorials it matches the human eye response best (between 400-800 nm in the visible light portion of the EM spectrum (Scherz, 512-514)). Its visual depiction can be seen in Part A of Figure 17 below. It is passive because it does not require a power supply to operate. A semiconductor's resistivity lies between a conductor and insulator depending on if it is doped with another material, temperature, and external energy.

In the LDR's case, the light photons excite more electrons in the valence band to cross the band gap to the conduction band, reducing resistance and allowing current to flow more freely. In the dark, resistance is in the megaohms since very few electrons are excited, but in the light, the large number of excited electrons leads to a resistance of only a few hundred ohms (Scherz, 512-514). This relationship is demonstrated in Figure 17, where light, or illumination, is denoted using lux on the horizontal axis (unit for light present on a unit of surface area, according to Collins Dictionary) and resistance is given in ohms on the vertical axis.

As shown in the bulb circuit in Part B of Figure 17 below, the photocell can be modeled as a variable resistor controlling the current based on the presence of light (Haraoubia, 1-81). A high resistance from darkness would dim or turn off in the bulb off while a low resistance from light would turn the bulb on and increase its brightness. In fact, it is commonly placed in a voltage divider. It would be in series with a fixed resistor where the output voltage would be measured in between the resistors. The output voltage would be based on the following formula: $V_{out} = \frac{R}{R_{LDR}+R}$ if the R_{LDR} is above the fixed resistor R and$V_{out} = \frac{R_{LDR}}{R_{LDR}+R}$if the R_{LDR} is below the fixed resistor. If the LDR is below the fixed resistor, the output voltage will increase while the light decreases. If it is above the fixed resistor, the output voltage will decrease as the light decreases (Scherz, 512-514).

Its functionality is put to use in the light sensing relay switch. A relay is an electromechanical switch that is activated by one circuit to produce greater current in another circuit (Scherz, 512-514). For an LDR switch, the voltage divider with the photocell feeds into the base of a BJT transistor, turning the transistor off and on. When this transistor is on, it turns on the relay by producing the required level of collector/emitter current; and when the BJT is off, the collector/emitter current is zero which deactivates the relay (Scherz, 514).

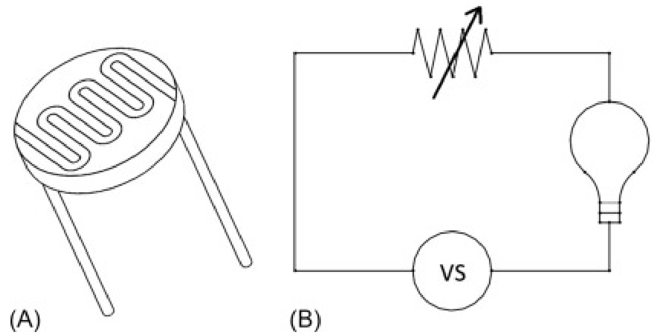


Figure 17: (A) Photoresistor. (B) Basic Bulb Circuit where photoresistor is represented as a variable resistor. (Christenson, Handbook of Biomechatronics)

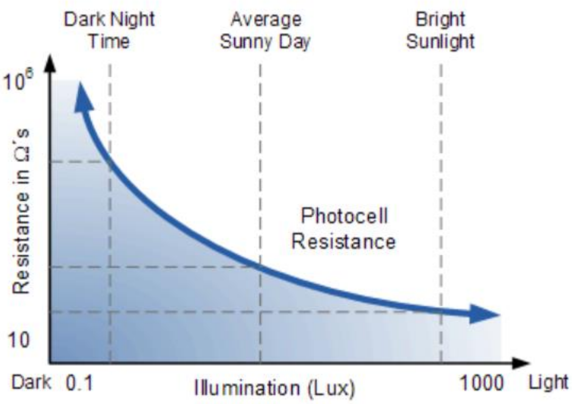


Figure 18: Light Presence versus Resistance for an LDR. (Electronics Tutorials)

3.1.5.2 Photodiodes

Photodiodes are semiconductor devices that act like a current source in the presence of light. They are PN junction silicon or germanium devices that are housed in a metal case with a clear window or a transparent container. The smaller the surface area, the faster its response time. PN junctions, or diodes, are a p-type semiconductor (anode, more holes) and an n-type semiconductor (cathode, more electrons) connected together. When light shines on it, holes in the p-type side are pushed to the n-type side which creates conventional current (Scherz, 514-515).

Diodes are active devices whose current is controlled by the light incident on them. They are active because all diodes require a certain voltage (which will be provided by light energy here) across it to turn on. When the diode is forward biased, as in a positive voltage across the diode, the voltage-current relationship is technically exponential but modeled as a linear relationship. Due to their linear light/output current relationship, photodiodes with this configuration are useful in light meter circuits, which are used in cameras, light meters, laser / imaging systems (Electronics Tutorials). Reverse bias, negative voltage across the PN junction, produces leakage current whose value grows if the intensity of light upon it grows. As shown below in Figure 19, dark current, or very few electron/hole pairs, occurs at 0 lux. But the current curves become higher with greater light presence. Reverse bias photodiodes are applicable for photoconductive networks that require more current than the positive bias can provide. There will be a battery negative with respect to the photodiode in order to increase current and reverse bias the diode (Scherz, 515). For both biasing modes, this leakage current is in the µA range and is difficult to detect with other electrical components without amplifying transistors or operational amplifiers (Electronics Tutorials). On the other hand, they are ideal for infrared or red frequencies and have a fast response time due to their direct light intensity/current relationship (Scherz, 514).

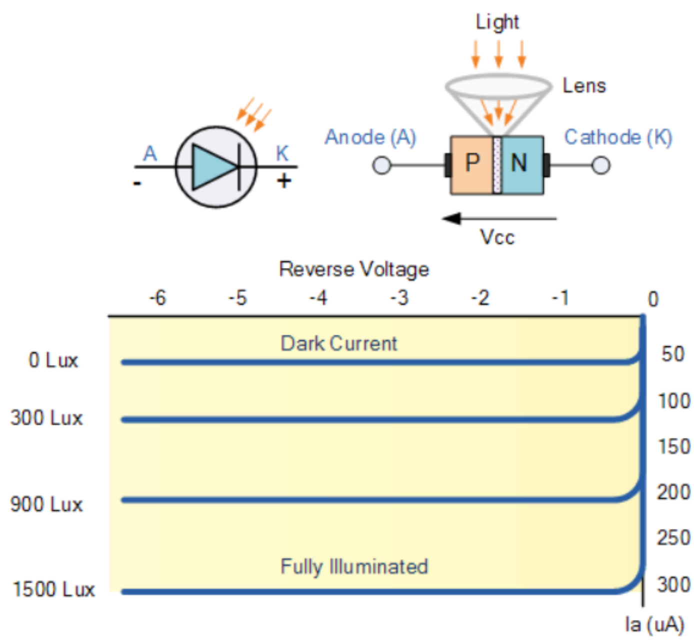


Figure 19: Operation and IV Curve of the Photodiode in Reverse Bias Mode. Source: Electronics Tutorials

3.1.5.3 Phototransistors

Phototransistors are transistors that are powered on and off by light. There are two types of phototransistors: photobipolar or photoFETs. Photobipolar transistors are light-sensitive BJTs which are current-controlled while photoFET transistors are light-sensitive FET transistors which are voltage-controlled (Scherz, 517). However, despite FET's greater sensitivity, photo BJT transistors are electrically stronger than FET transistors and thus will receive greater focus.

Phototransistors are in a clear case or a metal case with a clear window at the front with two metal terminals (or three terminals if more output current is required). The two-lead transistor would only have the collector and emitter terminals because the base region would be replaced with a light-sensitive region that will produce the input current. The three-lead transistor has an additional base region (and thus terminal) to produce more input current. BJT transistors typically used in the npn configuration, where when voltage (or in this case, light) energizes the electrons in the middle P junction (base) to move to the lower N junction (collector), which is the base current. This action leaves holes in the P junction, which electrons in the upper N junction (emitter) move to fill, which leaves holes. Thus, collector current flows in the direction of holes as long as base voltage is provided (Scherz, 518-519). BJT transistors are like diodes in that they are active semiconductors that control current, but the transistor can amplify current by a factor of 50 or 100, which results in greater sensitivity than the photodiode (Electronics Tutorials).

Shown in Figure 20 is the pictorial representation of the BJT phototransistor with its current-voltage characteristic curves. The light incident on the BC region will result in a small base current that will be amplified into a much larger collector current. With no light, dark current in the μA range results. The greater the light presence, the greater the collector current. Thus, the collector current curves will increase as the lux values increase (Electronics Tutorials). Notice how the collector current is in mA, a much larger quantity than the output of the photodiode.

Another phototransistor configuration used is the Darlington phototransistor. The Darlington transistor is two BJT transistors in parallel with each other. The transistor behind the other provides its amplified current into the base of the other, which results in a much greater overall collector current and higher sensitivity (Electronics Tutorials). The tradeoff is that due to their increased surface area, they have slower reaction time compared to the single phototransistor (Scherz, 519).

Examples of circuits using discrete phototransistors are the light-activated relay (where one phototransistor controls the power transistor to turn on and off a relay), the receiver circuit (lightwave detector/amplifier), and the tachometer (which uses light pulses to measure frequency, and these light pulses are detected and inputted by the phototransistor) (Scherz, 520). Photothyresistors or silicon-controlled rectifiers (SCRs), optoisolators, and fiber optics are examples of devices that incorporate phototransistors into their designs. SCRs are semiconductor switches activated by light, and optoisolators connect isolated circuits in the presence of light on phototransistors (Scherz, 521-522). In fibre optics, phototransistors are used at the receiving end of the fiber optics cable, which transmits data as light waves via optics (Scherz, 524).

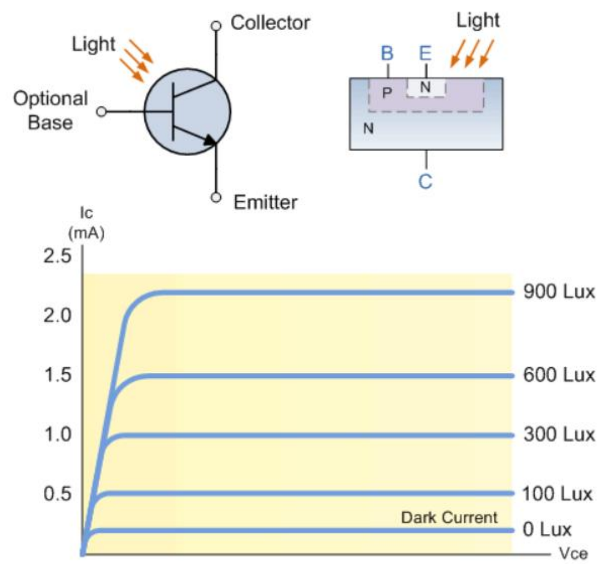


Figure 20: Operation and IV Curve of the Phototransistor. Source: Electronics Tutorials

3.1.6 Temperature Sensors

A temperature sensor detects levels of heat energy in order to provide a temperature reading. Heat, or kinetic energy, is generated by atom movement: more heat is produced if there is more atom activity. They operate by either direct or indirect contact with what they are measuring. Through direct contact, the heat energy of the atoms in one object is transferred over to the atoms in the sensor, also called conduction (Electronics Tutorials). Via indirect contact, heat is measured by either radiation, transfer via electromagnetic waves emitting from a warm body (Physics Hypertextbook), and convection, transfer by air or gas circulation from the source to another object (HyperPhysics). Convection is the most common method of heat transfer (Wikipedia). The following types of temperature sensors discussed below will be the thermocouple, analog and digital thermometer ICs, resistive temperature sensors, and thermistors. For this project, they will monitor how much heat a plant is receiving and thus inform the microcontroller when the plant should be shaded.

3.1.6.1 Thermistor

Thermistors or thermal resistors change the resistance based on the current temperature change. They are made out of nickel or cobalt oxides in a ceramic, circular flat disk with two metal terminals (Electronics Tutorials). There are two types of resistance temperature relationships for thermistors: the more popular NTC, negative temperature constant, and PTC, positive temperature constant. Both are visualized in Figure 21 below. For NTC the relationship is an inverse exponential relationship: the greater the temperature the lower the resistance. For PTC, it is a direct exponential higher relationship: temperature results in a higher resistance. This exponential relationship can be seen mathematically in the following formula: $\frac{1}{T} = \frac{1}{\beta} ln(\frac{R}{R_0}) + \frac{1}{T_0}$. R_0 and T_0 are the initial resistance for the specific thermistor and temperature (which is typically room temperature (25°C) and the resistance at this temperature or provided in the datasheet). β is the temperature constant for the specific thermistor, T is the new temperature, and R is the new resistance due to the new temperature). As shown in Figure 21 below, the thermistor can be measured via voltage divider, where it would be in series with a fixed resistor and that would change the resistance-temperature relationship from exponential to linear. If the thermistor equation is plugged into the voltage divider formula, the following output voltage formula is acquired: $V_{out} = \frac{R_1}{R_1 + (R_0 e^{\beta(\frac{1}{T} - \frac{1}{T_0})})} \times V_{in}$(Scherz, 529-530).

The output of the voltage divider can be connected to the ADC input of a microcontroller and converted to a temperature value via code. Thermistors are very sensitive to rapid temperature changes but have a limited temperature range (-40°C - 125°C) (Electronics Tutorials).

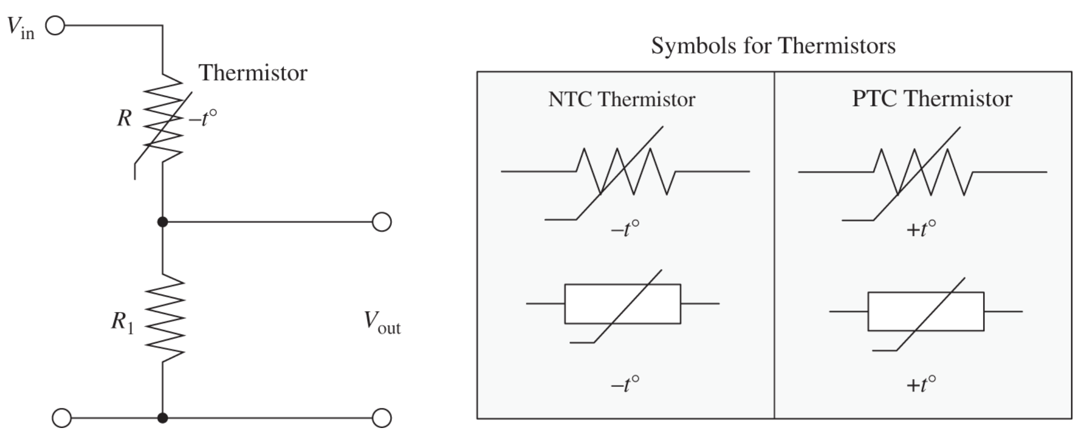


Figure 21: PTC and NTC Thermistors and Its Voltage Divider Network. Source: Scherz, *Practical Electronics for Inventors*

3.1.6.2 Resistive Temperature Detectors

Resistive temperature detectors (RTD) change their resistance based on temperature change. Unlike a thermistor, RTDs use the purer metals such copper, nickel, and platinum, provide a linear resistance-temperature relationship, and have a wider temperature range (-260°C - 800°C) but reduced sensitivity (Scherz, 532). This relationship is shown via the following equation: $R(T) = R_0(1 + \alpha[T - T_0])$. T_0 and R_0 are the reference temperature and resistance at the temperature; T and R are new temperature and the resistance at it; and α is the material's temperature coefficient of resistance (TCR). Typical T_0 and R_0 are 0℃ at 100 Ω which increases based at the rate of α (Ida, 71). Like a thermistor, its value can be measured using a voltage divider and Wheatstone bridge. Due to the high cost of platinum, RTDs cost more than thermistors (Electronics Tutorials).

3.1.6.3 Thermocouples

Thermocouples are two different metals joined and measuring heat at one junction ("hot" junction) and a reference ("cold") junction at the other end, which is usually room temperature. It depends on the Seebeck effect: each metal type undergoing a temperature change will produce a different voltage change. With two metals joined at one end, their voltage difference can indicate what the junction temperature is (Scherz, 531). There is no voltage difference if both metals have the same temperature. The temperature can be found using the output voltage, the reference temperature, and that thermocouple's lookup table (Electronics Tutorials). A good representation of the output voltage and temperature relationship is the following equation: $V_{out} = \alpha(T_H - T_C)$. The α value is the Seebeck coefficient, a material constant dependent on temperature, and T_H and T_C are the hot junction temperature and cold junction temperature respectively (Abdolvand). There are various thermocouple classes such as Type E (Nickel Chromium/Constantan) and Type K (Nickel Chromium/Constantan). Since the thermocouple output only changes about millivolts per 10℃, an op-amp is added to amplify the output to volts to provide a better reading. Unlike the previous temperature sensors, thermocouples have a very wide temperature range (-200℃ - 2000℃) (Electronic Tutorials).

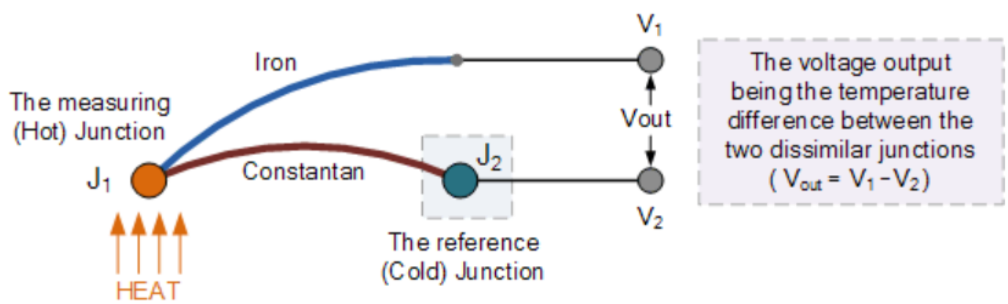


Figure 22: Thermocouple Operation. Source: Electronic Tutorials

3.1.6.4 Analog and Digital Thermometer ICs

Thermometer ICs are semiconductor chips that can measure temperature. The difference between analog and digital thermometers is that the analog IC represents the output as a continuous range of voltage values, such as any values between 2 - 5 V while the digital IC can only output discrete voltage values, such as only 1's and 0's (bits). They have a temperature range around -50℃ - 125℃. The resolution of analog ICs is slightly higher than the digital ICs (a few degrees vs. half a degree). While the analog ICs are easy to interconnect with other components and provide a wider range of values, the digital ICs are also easy to interconnect, have fewer errors than the analog due to restricted output values, but can communicate with microcontrollers well (Scherz, 533). However, both provide the same temperature range as thermistors but are more expensive (Scherz, 535).

3.1.7 Soil Moisture Sensors

Soil moisture sensors measure the water content in soil. There are three main kinds of soil moisture sensors: volumetric, tensiometers, and solid-state sensors. Volumetric sensors measure water indirectly from the soil's other properties such as neutron concentration, capacitance, and relative permittivity. Tensiometers detect tension between soil and water to measure water. Solid state sensors measure water by detecting conductance between two electrodes in the soil (Buchen). Since volumetric sensors and tensiometers work best in wetter soil and higher-end versions of all three sensors can cost hundreds of dollars, this section will focus on low-cost solid-state sensors.

Soil resistivity can be measured because of the electrolytic nature of water in soil (the salt presence, temperature, two different mediums between soil and water) (Wikipedia). Resistivity and conductivity are inversely related. Since water is a conductive material, more water in the soil increases conductivity (Buchen). This change indicates that the soil moisture sensor is a variable resistor whose voltage will then be converted into moisture value via microcontroller code. The sensor might require some calibration based on the soil type it is in. More corrosion will occur due to increased conductivity because the moist, chemically reactive environment would slowly damage even coated sensor pads. To reduce corrosion damage, limit conductivity by turning off a sensor's power until needed (Al-Mutlaq). Soil resistivity can indicate the soil volume's corrosive level. The higher the resistivity, the lower the corrosion. Inversely, the higher the conductivity, the higher the corrosion. For example, according British Standard 1377, soil resistivity of a 100 Ωm is slightly corrosive while one about 10 Ωm is highly (Wikipedia). Overall, the soil moisture sensor is crucial in determining when to turn on the plant's irrigation system.

3.1.8 WiFi Modules

WiFi modules communicate wirelessly and would be used to transmit data between the MCU and the user application. WiFi modules communicate to and from the Internet (from the user's phone to the local access network to the user application) (curiousparti - YouTube).

WiFi is a part of IEEE 802.11 wireless standards, which determine the specifications such as application, frequency band, and radio wave type of a particular WiFi technology such as 802.11a and 802.11b (TutorialsPoint). The WiFi system involves the transmission line, modem, wireless router, and end devices. If an application is fulfilling a user's request, data from the internet is converted from digital to analog so that it can travel over the transmission line to the user. The modem converts data from the transmission line from an analog signal into a digital one and sends it to the wireless router. The wireless router then communicates this data to the user's WiFi connected device (phone, tablet, TV, etc). If the user then makes a request, the process is repeated but in reverse (curiousparti - YouTube). There are three main WiFi security protocols: Wired Equivalent Privacy (WEP), Wi-Fi Protected Access (WPA), and Wi-Fi Protected Access II (WPA2), with WPA2 being the newest and the most secured (Fitzpatrick). For this project, a WiFi module compatible with the microcontroller will act as an end device, which will communicate to a user's nearest WiFi router. This router will transfer the data to the project application database on the Internet.

3.1.9 Microcontroller

A microcontroller is an embedded system with a CPU, memory, and various input and output ports. It can perform a wide variety of tasks. The functionality of the microcontroller varies from a simple timer to a calculator that can perform complex functions or a device that can process stunning images and send them to a screen to be displayed. For many devices, the microcontroller works as the "brain" of the system. It processes code, stores data, and sends messages to the other working components. Without it, the device would be lifeless and have very little capability.

The term microcontroller refers to the chip that performs all processing. The microcontroller is typically placed on a development board. The board itself has several other components that will allow the microcontroller to complete all necessary tasks as well as communicate with the other components within the system. It is important to distinguish between the two as they both will be studied individually.

The development board plays a vital role in this project. It will function as the main control center for the entire system. To start, the board will be receiving data from the sensors about the current state of the plant. This data will be used to determine how the plant is doing and if any changes should be made to its care. If a change should be made, the microcontroller will use the board to send a command to the irrigation, shading, and/or rotational systems accordingly. It is also important for the microcontroller to have a lot of storage. It will be storing a lot of data from all components of the system and therefore, needs extra registers to keep track of it all. If the microcontroller does not have enough, the board itself will provide extra. Next, the microcontroller will need to communicate with the application using a Wi-Fi module. It will be receiving data from the application about the appropriate care for the plant and will need to adjust its methods accordingly. This will be implemented by connecting the Wi-Fi module to the development board which will then be connected to the microcontroller itself. The microcontroller will utilize timers to determine the appropriate time for watering the plant or implementing the shading system. Subsequently, the microcontroller must be compatible with all sensors and modules. This is important as a non-compatible microcontroller will cause the entire project to fall apart as a lack of communication between the parts means that nothing can get done. Of course, because the project involves the use of numerous sensors and modules, the microcontroller must have many I/O ports. That way, it can communicate with all parts of the system simultaneously. These ports will be made available on the board itself and will connect the brain of the system to all of its components. Finally, it is important that for the cost of the microcontroller to be as little as possible. This will provide a low production cost which will keep the market price low. All of these requirements will be taken into consideration when determining the appropriate microcontroller and development board for the project.

There are other features of the microcontroller that will be taken into consideration but are not vital to the success of the project. For example, the clock is an important feature of all microcontrollers. It allows the device to process code, perform tasks, and even measure time. With the amount of data that will be processed as well as the timers that will be used, a clock plays a vital role to this project. However, the clock speed is not as important. Although it would be nice to implement the clock at a faster speed, it is not necessary for this project. The plant will need to be watered in a timely manner; however, this is not a task that has to be done right away. The plant can wait for a short period of time if necessary. Therefore, sacrificing the maximum clock speed to purchase a cheaper microcontroller is acceptable. Another aspect of the clock is the accuracy. Using a crystal oscillator will assure precision with keeping time. An RC clock may startup faster, but it is less accurate and reliable. For other projects, the crystal oscillator is a clear choice as accuracy is key to their success. For this project, however, accuracy is less important and therefore, the use of the RC clock is acceptable.

It is important to note that although much research has been conducted on this varying microcontrollers and boards on the market, the development board itself will not be used in the final product. For this project, the board will only be used in the prototyping stages for testing of the code and compatibility with the sensors and modules. Once prototyping is complete, all but the chip on the board will be discarded. The chip itself will be placed on a new PCB that was designed specifically for this project. Although the development board will not be used for the final project itself, it must meet all project requirements so that it can provide a stable setting for testing. The board must have all desired functionality so that everything can be perfected before the PCB is used.

3.1.10 Application Design Software

This project will include an application. The application will be used on a mobile device and will allow the user to input data about the plant. This piece of software will play a vital role in the project as it will provide the microcontroller with all necessary data for taking care of the plant and help it determine when to signal the other components. Without it, the only way to insert data about the plant would be to edit the original code within the microcontroller. This task is not suitable for the target audience and therefore, this is not a relevant solution. Therefore, some sort of method for inserting data must be created. An application is a clear choice as it is an easy way to upload data and it is acceptable to assume that the average person within the target audience will have access to a device.

3.1.11 Motors

Within the mechanical components of this project, several different motors will be used to drive different mechanical parts. We need to find 3 motors each with a large enough power output to overcome the moment of inertia of each of their respective loads. A motor for the rotational system, a motor for the moving parts of the shading system, and a motor for the pump. When considering motors, there are a variety of different choices that one could choose from. Motors range in many different sizes, shapes, and powering methods. For instance, for a larger load, one may want to use an AC motor. With AC motors, there are two main types of motors, Synchronous motors and Induction motors. With Synchronous motors, the speed is synchronized with the frequency of the supply current, and therefore these motors are useful for a consistent speed under a variety of loads. With Induction motors, the motors use electromagnetic induction from magnetic fields in order to produce torque in the motor. These motors usually come in either a single phase, or three phase variant, and are used for a variety of different purposes, from household appliances, to industrial scale equipment. With DC motors, there are a variety of different types of motors to choose from, each belonging to one of two major categories. Those categories are: brushed motors, and brushless motors. The main difference between brushed and brushless motors is that with the brushed motor, the commutator is connected directly to the power supply through a brush, while in a brushless motor, the power is converted through electromagnets that transfer their energy to the rotor through their magnetic field. Brushed motors tend to be cheaper, and easier to control, however with brushed motors, the brushes may need to be maintained after prolonged use. Brushless motors, on the other hand, usually have a much longer lifespan, better efficiency, and lower maintenance overall, however, they tend to be more costly than brushed motors. Comparing these motors for our project, for the size, cost, and power requirements, one can easily narrow down that some form of a DC brushed motor should be used. Because our product's moving parts don't need much power, using an AC motor would be overkill. Also, a typical AC motor would require too much power for what we are looking at. When it comes to brushed, vs brushless motors, both are good, but it seems that a brushed motor would fare best within our cost and power requirements.

3.2 Part Selection

In this section, all the selected components are discussed along with summary tables that compare different available elements and the final decision based on different parameters.

3.2.1 Power System

The power system is a key feature of the design since it is in charge of powering all the components to make the overall system work. For this reason, it is of great importance that the power system is well designed to provide the required reliability for the entire system to work at optimum conditions. To design a solar power system, different subsystems must be designed, and some aspects must be considered to fulfill the power requirement of the system.

An off-grid solar power system can be designed by following simple steps. First, the required amount of power needed to energize the entire system must be determined. This can be achieved by performing load calculations where everything that is going to be powered by the solar system must be considered. Then, the amount of batteries needed to store the power generated by the solar panel must be determined. Here, considerations as the duration of the stored power, a secondary power source, the place to store the batteries, and the voltage battery bank needed must be taken into account to provide a reliable system that power all the components compressed in the structure. Then, the quantity of solar panels needed must be calculated based on the location and time of the year. It is well known that different parts of the world receive different amounts of light depending on the location and the time of the year. Places near the equator receive approximately the same number of hours of sunlight in summer and winter. However, this is not the case for places above the Tropic of Cancer or below the Tropic of Capricorn. Then, a solar charge controller must be selected. This device sits between the solar panel and the batteries. There are two major types of technologies for this device: PWM and MPPT. Both technologies will be studied to determine the best fit for the project design. Then, an inverter must be selected if AC loads are to be powered. Finally, the system must be balanced. Here, factors such as the fuses and breakers for over current protection, breaker boxes, solar panel mounting, and wire size must be considered to design an efficient and reliable off-grid power system.

In addition to the previous components required, a voltage regulator will be needed to regulate the voltage from the power system to the microcontroller. Since the microcontroller requires a small voltage, a step-down device, voltage regulator, will be required. There are different types of voltage regulators. These will be researched and studied to select the best fit for the design.

3.2.1.1 Power Requirement

Since a microcontroller and different sensors and mechanical parts need to be powered in this design, the power requirement is a key quantity that must be determined to assure the system is capable of powering all the systems running together.

The sensors will consume all together an approximate maximum power of 350.36mW. The light sensor (VEML6030) will consume a maximum of 50mW, the photoresistor a maximum of 200mW, the temperature sensor (TMP102) a maximum of 0.36mW, and the WiFi module (ESP8266) a maximum of 100mW. The moisture sensor (SEN-13322) will be powered via a digital pin on the microcontroller which does not draw power directly from the power system.

The mechanical parts are composed of a shading, rotation, and watering system. The motors used for both the shading and rotation system will require a maximum power of 7.2W each. The water pump for the irrigation or watering system will need a maximum power of 3.6W. Altogether, these mechanical systems require a maximum power of 18W.

On the other hand, the microcontroller chip ATmega4809 will require a max power of approximately 100mW. By adding all the power requirements for each sensor, mechanical part, and the microcontroller, the total power required is around 18.45036W which can be rounded to 20W to overcome variations. However, further calculations must be made in order to determine the Watts per hour required for the system to run all the components based on the operation period of each component.

It is estimated that around 22 watt-hour per day are needed for the system to run. Based on this measurement, different calculations were made using the altE Off-Grid Calculator. This calculator provided us with the battery bank capacity in watt-hour and amp-hour based on the watt-hour per day required and the selected battery bank voltage. With the provided watt-hour per day measurement, a selected battery bank voltage of 12V, two days of backup selected in case of cloudy/rainy days, and an average temperature of 80°F, the battery bank was calculated to have a minimum capacity of 112 watt-hour or 10 amp-hour. This is assuming only a 50% discharge to the battery to optimize battery life.

On the other hand, to determine the solar panel and solar charge controller sizing, the same calculator was used. Here the nearest location to us was selected, Tampa, Florida. This provided us with the average sun-hours for our location, being that 4.4 hours. Based on the previous calculations made, the total wattage of solar panels needed was determined to be 6.5W or 0.01kW. Due to design size constraints, one solar panel will be used. Being that the case, it was calculated that only one solar panel of 10W was needed to supply the required power to the battery to charge and power the overall system. In addition, based on these calculations, the solar charge controller size was determined to be 1A, which means the solar charge controller must handle this amount of current.

3.2.1.2 Rechargeable Batteries

As mentioned in the relevant technology section of this report, there are different types of rechargeable batteries. For design purposes, the lead-acid, nickel-cadmium, nickel-metal hydride, lithium-ion, lithium-ion polymer, and alkaline batteries will be compared to select the best fit for the project design in order to satisfy different requirement specifications and standards.

The project design consists of different sensors, mechanical devices, and a controller board that need to be powered. The initial design will consist of a rechargeable battery powered by solar panels. However, the fact that varied weather can occur at any time can affect the energy generation from the solar panels to power the battery to its maximum. Due to this fact, an additional battery can be added to operate the system when the solar panels do not receive the required amount of light. On the other hand, the system can include a charging port to charge the battery via a plug connection. This is something that will be tested to determine the best approach to the overall project design.

Another fact that must be considered is that powering mechanical elements along with electrical elements from the same power supply can have consequences on the overall design operation. Mechanical elements such as DC motors tend to produce a lot of noise. This noise can interfere with other electrical and mechanical components of the system. In fact, this noise generated can have an impact on the power supply of the system, making it unstable and unable to provide the required amount of power to other elements. This fact will be studied as well to determine if an additional battery must be needed to power the mechanical components alone. This is something that must be tested with the selected components to observe the behavior of the overall design under certain conditions. Once all the components are selected and tested, a prototype can be created to test different subsystems and make the pertinent changes on the power supply design of the system.

3.2.1.2.1 Lead-Acid Batteries

The lead-acid battery is inexpensive and simple to manufacture. Its technology is mature, reliable, and well-understood. Its self-discharge rate is one of the lowest in this category of batteries. These batteries require low maintenance and are capable of discharge at high rates.

However, they cannot be stored in a discharged condition. Its low energy density limits their use in certain applications. The number of full discharge cycles is limited making them good only for applications that do not require constant deep discharges. In addition, these batteries are categorized as environmentally unfriendly due to the electrolyte and lead content which creates a concern in possible accident cases of the flooded lead acid batteries. Due to this concern, flooded lead acid batteries have some transportation restrictions.

3.2.1.2.2 Nickel-Cadmium Batteries (NiCd)

Nickel-cadmium batteries have some advantages as well as some limitations. Some of their advantages include their fast and simple charge, and their high number of charge and discharge cycles. With a well provided maintenance, these batteries can provide over 1000 charge/discharge cycles. They provide good performance at low temperatures which allows them to recharge at low temperatures. In addition, they have a long shelf life and are simple to store and transport. These batteries are considered to be sturdy even if they are not managed properly. In reference to marketing considerations, these batteries are economic based on their cost per cycle. Also, they come in a wide range of sizes and performance options which is a good characteristic since it allows the use of this battery in different applications where size and performance are important requirements.

However, some of their limitations include their relatively low energy density and memory effect. Their memory effect requires the battery to be exercised periodically to prevent it. As lead-acid batteries, nickel-cadmium batteries are considered to be environmentally unfriendly due to the containment of toxic metals. In addition, these batteries have high self-discharge which makes them need to be recharged after storage.

3.2.1.2.3 Nickel-Metal Hydride Batteries (NiMH)

Nickel-metal hydride batteries compared to nickel-cadmium batteries have from 30 to 40 percent higher capacity. They have potential for higher energy densities. The memory effect in these batteries is less prone compared to that of nickel-cadmium batteries. This makes the periodic exercise cycles to be less required. In addition, they are simple to store and transport and are considered to be environmentally friendly since they only contain mild toxins which can be recyclable.

On the other hand, these batteries have a limited service-life meaning if the system requires repeatedly deep cycles at high load current, the performance of the battery deteriorates after several cycles. In addition, these batteries have a limited discharge current since its cycle life reduces after several discharges with high load currents. The charge algorithm of these batteries is of higher complexity compared to that of a nickel-cadmium battery. These batteries tend to generate more heat while charging and take longer to recharge compared to nickel-cadmium batteries. Also, these batteries have a higher self-discharge, and their performance reduces at high temperatures. Furthermore, nickel-metal hydride batteries require a high maintenance meaning they must be full discharge to prevent crystalline formation, and they are more expensive than nickel-cadmium batteries for about 20 percent.

3.2.1.2.4 Lithium-Ion Batteries (Li-ion)

Lithium-ion batteries have a higher energy density which allows higher capacities. These batteries have a relatively low self-discharge being that less than half compared to nickel-cadmium and nickel-metal hydride batteries. Also, they require low maintenance since they do not need to be periodically discharged and have no memory effect.

On the other hand, these batteries require a protection circuit to limit the voltage and current. Also, they can age if they are exposed to low temperatures and have a moderated discharge current. If these batteries are to be transported in large quantities, there are certain restrictions that control their transportation. On the marketing side, they are more expensive to manufacture compared to that of a nickel-cadmium which can be 40 percent lower in price. In addition, they are not fully mature meaning that small changes in the metal and chemical reactions could affect battery test results.

3.2.1.2.5 Lithium-Ion Polymer Batteries (LiPo)

Lithium-ion polymer batteries are flexible from factor which means the manufacturers have more freedom in manufacturing them since they are not bounded by standard cell formats. In addition, these batteries have a light weight since they are composed of gelled electrolytes which allows in some cases the metal shell to be removed. Also, they have improved safety functions which are resistant to overcharge which prevent electrolyte leakage.

However, these batteries have a lower energy density and a decreased cycle count compared to regular lithium-ion batteries. In the marketing side, these batteries are expensive to manufacture.

3.2.1.2.6 Alkaline Batteries (RAM)

Alkaline batteries have several advantages which include a longer shelf life, a much higher energy density, and a good performance at low temperatures. In addition, these batteries can be used hundreds of times if it is recharged after it has been used to only 25 percent of its capacity. These batteries do not represent a threat to the environment when disposed of. Also, they retain 90 percent of their capacity even if it is stored at room temperature for a few years.

However, as every battery, alkaline batteries have their limitations. These batteries are bulkier than other types of batteries. Also, they have a higher internal resistance which causes the output to be reduced. If the battery charger is defective, alkaline batteries are more likely to explode. In addition, if these batteries are kept in a non-used device for a long time, they can leak and damage the device being powered by this battery due to the corrosive nature of this leaked material.

3.2.1.2.7 Final Decision

Despite the variety of rechargeable batteries available at the market, the most commonly used batteries for solar systems are lead acid and lithium-ion batteries. Based on the research of these two batteries, the lithium-ion battery was selected for the project design based on different parameters.

Lithium-ion batteries are lighter and more compact than lead acid batteries. This is an important characteristic to consider in this project design since the weight and size of the product is intended to be efficient, compact, easy to install and handle. In addition, they have a higher depth of discharge (DoD) and longer lifespan than lead acid batteries. This is an additional important characteristic for the design since it is intended to reduce the human interaction to grow and take care of a plant. This will reduce this interaction since lithium-ion batteries require low to no maintenance. This will prevent the consumer from changing the battery or providing a constant maintenance of the battery as is needed with lead acid batteries. Lead acid batteries tend to have a reduced lifespan which requires the verification of the acid contained in the battery.

In addition, lithium-ion batteries tend to have more cycle life than lead acid batteries. Lead acid battery’s cycle life is around 200 to 300, while lithium-ion battery’s cycle life is around 500 to 1000 to 80% of initial capacity. In addition, the charging time of lithium-ion batteries is faster than lead acid batteries. Lithium-ion batteries charge in an average of 2 to 4 hours, while lead acid charges in 8 to 16 hours.

One downside of lithium-ion batteries is their cost. They tend to be more expensive than lead acid batteries. Their price can be two times or more the cost of a lead acid battery depending on the application's requirements. In addition, these batteries require a protection circuit to maintain voltage and current within safe limits since their overcharge tolerance is very low. However, with well-designed protection systems and controlled voltage and currents, lithium-ion batteries provide more advantages to the project design than the lead acid batteries.

After discussing the advantages and limitations of each rechargeable battery considered in this project, the following table summarizes some important quantities and characteristics of each battery to select the best fit for the design.

	Lead-Acid	NiCd	NiMH	Li-ion	LiPo	Alkaline
Gravimetric Energy Density (Wh/kg)	30-50	45-80	60-120	110-160	100-130	80 (initial)
Internal Resistance (mΩ)	<100 12V pack	100 to 200 6V pack	200 to 300 6V pack	150 to 250 7.2V pack	200 to 300 7.2V pack	200 to 2000 6V pack
Cycle Life (to 80% of initial capacity)	200 to 300	1500	300 to 500	500 to 1000	300 to 500	50 (to 0%)
Fast Charge Time	8-16 h	1h typical	2-4h	2-4h	2-4h	2-3h
Overcharge Tolerance	High	Moderate	Low	Very low	Low	Moderate
Self-discharge / Month (room temperature)	5%	20%	30%	10%	-10%	0.3%
Cell Voltage (nominal)	2V	1.25V	1.25V	3.6V	3.6V	1.5V
Load Current -Peak -Best Result	5C 0.2C	20C 1C	5C 0.5C or lower	>2C 1C or lower	>2C 1C or lower	0.5C 0.2C or lower
Operating Temperature (discharge only)	-20 to 60°C	-40 to 60°C	-20 to 60°C	-20 to 60°C	0 to 60°C	0 to 65°C
Maintenance Requirement	3 to 6 months	30 to 60 days	60 to 90 days	Not required	Not required	Not required
Typical Battery Cost	$25 (6V)	$50 (7.2V)	$60 (7.2V)	$100 (7.2V)	$100 (7.2V)	$5 (9V)
Cost per Cycle	$0.10	$0.04	$0.12	$0.14	$0.29	$0.10-0.50

Table 2: Comparison Table of Rechargeable Batteries Estimated Specifications

Once an exact power requirement is established based on the selected sensors and mechanical systems, the best lithium-ion battery for the entire design will be selected.

3.2.1.3 Solar Panels

A solar panel will be a key component to recharge the batteries to supply the required voltage and power for all the subsystems of this design. However, solar panels must be selected cleverly to ensure they will provide the required amount of power. For this selection, the power per hour requirements for all the components must be determined to design a reliable power system at all the times the entire device operates. After performing some tests on a breadboard with the different sensors, motors and microcontroller chip, this will be determined.

There are different types of photovoltaic cells and solar panels in the market. The most common ones are monocrystalline, polycrystalline, and thin-film. Each type has its advantages and disadvantages regarding their cost, efficiency, performance, portability, flexibility, and aesthetics.

The composition of these different types of solar panels varies for each type. Both the monocrystalline and polycrystalline solar panels are composed of silicon wafers. These wafers are assembled in a matrix form based on rows and columns in a rectangular shape. They are then covered with a sheet of glass and framed together to create what is the solar panel itself. Even though both the monocrystalline and polycrystalline solar panels are composed of silicon wafers, their silicon composition differs. For the monocrystalline solar cell, as its name implies, the cells are made from a single, pure crystal of silicon. However, for the polycrystalline solar cell, as its name implies, the cell wafers are made from different fragments of silicon crystals meted together. On the other hand, thin-film solar panels are made from a variety of materials being the most common one cadmium telluride (CdTe), amorphous silicon (a-Si), and Copper Indium Gallium Selenide (CIGS). Cadmium telluride solar panels are composed of a layer of CdTe between transparent conducting layers. These layers are responsible for capturing the sunlight to generate energy. These types of solar panels are also protected by a top glass layer. Amorphous silicon solar panels are composed of non-crystalline silicone on top of glass, plastic, or metal. Copper Indium Gallium Selenide solar panels contain all four elements which are placed between two conductive layers, and electrodes placed on the front and back of the material. (*EnergySage*)

The appearance of each type of solar panel differed based on their composition and production. Monocrystalline solar panels usually have black cells due to the interaction effect of light and pure silicon crystals. Polycrystalline solar panels tend to have a bluish appearance due to the interaction effect of light and fragments of silicon. Both the monocrystalline and polycrystalline solar cells tend to be bulkier than thin-film solar cells. Thin-film solar panels' technology is thin and low-profile. They are slimmer since their cells are roughly 350 times thinner than the crystalline wafers. Their cell color can be either black or bluish depending on their composition. (*EnergySage*)

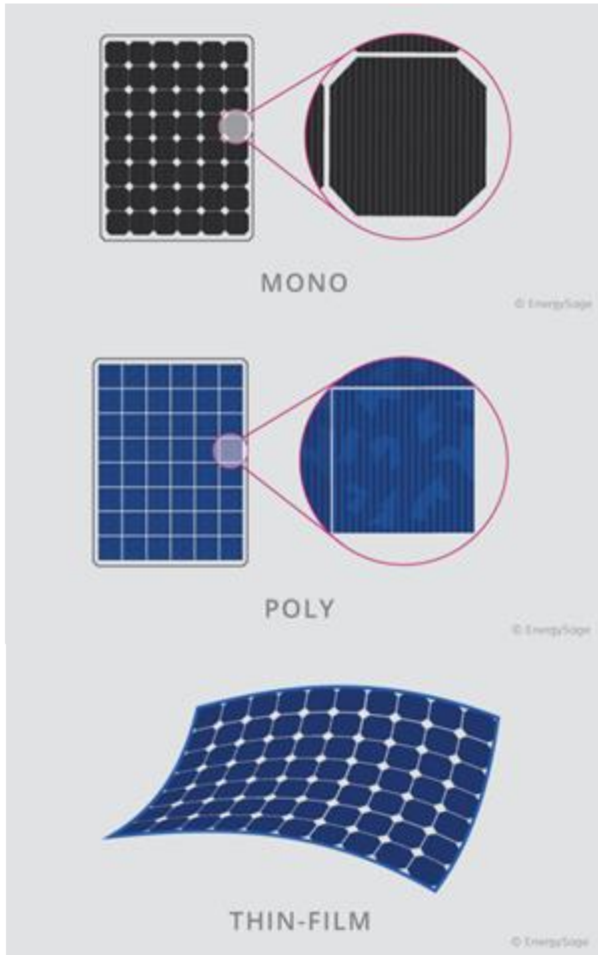


Figure 23: Appearance of Three Different Types of Solar Panels

(monocrystalline, polycrystalline, thin-film) *(Source: EnergySage – Permission Granted)*

In addition, the solar panel power and efficiency ratings differ based on each type. Monocrystalline solar panels tend to have higher efficiencies and power capacity than polycrystalline solar panels. Its efficiencies can be higher than 20 percent, while polycrystalline solar panel efficiencies are around 15 to 17 percent. Thin-film solar panels tend to have lower efficiencies and power capacities compared to monocrystalline and polycrystalline solar panels. Their efficiencies vary based on their composition, but they are usually around 11 percent. Regarding power generation, monocrystalline solar panels come in higher wattage modules providing more than 400 watts. Polycrystalline solar panels come in lower wattages, usually around 300 watts. However, thin-film solar panels power ratings vary depending on their size since they do not come in uniform sizes and monocrystalline and polycrystalline solar panels. (*EnergySage*)

Also, depending on the type of solar panel selected, the cost will vary. Monocrystalline solar panels tend to be the most expensive of the three types mentioned. Their higher cost is due to their manufacturing process since they are made from single silicon crystals. Polycrystalline solar panels are less expensive than monocrystalline solar panels since they are made from fragments of silicon instead of pure silicon. However, thin-film solar panels' cost depends on the composition of their cells. CdTe solar panels are the least expensive while CIGS solar panels are more expensive to manufacture than CdTe or amorphous silicon solar panels. (*EnergySage*)

After comparing all three different types of solar panels, it was concluded that the monocrystalline solar panels provide higher efficiencies and power ratings for the project design. Even though their price is higher than the other two types, efficiency is one of the engineering targets of this project design, so products with better efficiency ratings must be selected.

	Monocrystalline	**Polycrystalline**	**Thin-Film**
Composition	Pure Silicon	Fragments of Silicon	Variety of Materials (CdTe, CIGS, a-Si)
Appearance	Black cells	Bluish cells	Black or Bluish cells
Efficiency	>20%	15-17%	11%
Power Rating	>400W	~300W	Varies (depends on size)
Cost	$$$	$$	$

Table 3: Comparison of Different Types of Solar Panels

(Note: '$' symbolizes the cost of the solar panel. The more symbols, the higher the cost.)

After selecting the monocrystalline solar panel type for the project design, different available solar panels with these characteristics and the required wattage and voltage rating can be compared to select the best fit for our project. All the solar panels considered in the following table provide a power rating of 10W and a voltage of 12V. This is due to design sizing constraints.

Part #	81282	NPA10-12	RNG-10D-SS	1502511
Manufacturer	SolarSynthesis	Newpowa	Renogy	Banggood
Dimensions (inches)	11.5x11.5x0.9	14.37x7.68x0.91	10.6x13.4x1.0	8.43x7.24x0.12
Weight (lbs.)	2.6	2	1.2	0.37
Short Circuit Current (Isc – A)	0.62	0.68	0.62	1.96
Open Circuit Voltage (Voc – V)	21.88	21.6	21.6	14
Optimum Operating Current (Imp – A)	0.57	0.58	0.57	1.66
Optimum Power Voltage (Vmp – V)	17.5	17.00	17.5	12
Price	$35.00	$24.70	$33.99	$16.67

Table 4: Solar Panels Comparison Table

3.2.1.4 Solar Charge Controller

As for the solar panels, the solar charge controller is an important component of the power system. To design this power subsystem, the exact amount of power to be consumed needs to be determined. This calculation will assure the solar charge controller to be correctly sized to provide the correct amount since an improperly selected solar charge controller can result in losses on the power generated. These losses can add up to 50% which is bad for the overall power system of any device.

Solar charge controllers' main functions are to optimize the charging of the deep cycle batteries by the solar panels, and prevent electricity stored in the batteries from going through the solar panels when there is no sun. *(altE)* There are two major types of solar charge controllers: MPPT Solar Charge Controllers and PWM Solar Charge Controllers.

The selection of a solar charge controller will be based on the amperage and voltage characteristics since it will need to support the voltage of the solar panel array, and output to the battery bank's voltage. *(altE)*

The Maximum Power Point Tracking or MPPT solar charge controller can detect the optimum operating voltage and amperage of the solar panel array and match that with the battery bank. This feature makes the output power from the solar panel to be 15 to 30 percent higher than that obtained from PWM solar charge controllers. *(altE)*

MPPT solar charge controllers provide higher efficiencies since they use the entire power of the solar panels to charge the battery bank. These devices draw out the current of the panel at the maximum power voltage. However, their output is limited to avoid battery overcharging. These devices monitor and adjust the input to regulate the current from the solar system. This causes their efficiency to be higher, around 90% or more. *(Renogy)*

The Pulse Width Modulated or PWM solar charge controllers are robust and inexpensive. However, the nominal voltage of the solar array has to match the voltage of the battery bank since it does not have the ability of detecting the voltage and matching it with the battery bank as the MPPT solar charge controller. *(altE)*

The pulse width modulation process of these devices consists of regulating the flow of energy to the battery by reducing the current. These devices provide a series of short charging pulses to the battery which keep supplying power, in small amounts, to keep the batteries full. *(Renogy)*

3.2.1.5 Balance of System

Once all the exact power requirements, solar panel, and solar charge controller are determined, the system can be balanced by determining if it needs fuses and breakers for over current protection as well as how the solar panel is going to be mounted and the wires needed.

3.2.1.6 Voltage Regulator

The voltage regulator main function is to regulate the voltage generated in the battery bank, which is a 12V battery charged via solar panels, to provide an acceptable voltage for the selected microcontroller chip, the ATmega4809. This chip requires a 5V input voltage which requires a step-down voltage regulator to regulate the 12V coming from the battery bank to 5V to power the ATmega4809 chip. However, the prototype will be performed using the Arduino® Nano Every board which requires a higher input voltage. As the design is being developed, required adjustments will be made to the voltage regulator design to fulfill the input voltage requirements.

On the other hand, the sensors used in the system have an operational voltage of 3.3V making them to require a voltage regulator to regulate the 12V supplied from the battery into the 3.3V required for the sensors.

Due to the varied requirements of voltages for the system to operate on optimum conditions, different types and designs of regulating circuits will be designed and tested to select the best and most efficient ones for the final project design.

Different voltage regulating circuits will be considered such as linear voltage regulators, switching voltage regulators, and DC/DC converter designs generated on WEBENCH which are based on switching regulators.

3.2.1.6.1 Linear Voltage Regulator

Linear voltage regulators can produce a fixed output voltage or an adjustable output voltage. Since the required input voltage of the ATmega4809 chip is 5V, two fixed linear regulators will be considered: LM340A and LM7805. In addition, the adjustable voltage regulator LM317 will be considered and compared with the fixed voltage regulators mentioned before.

Based on Texas Instruments datasheets for these voltage regulators, the following quantitative measurements correspond to each regulator considered.

Feature	LM340A	LM7805	LM317
Operating Voltage	7.5V – 35V	7.5V – 35V	4.25V – 40V
Output Voltage (typical)	5V	5V	1.25V – 37V
Output Options	Fixed	Fixed	Adjustable
Unit Price	$0.90	$1.54	$1.69

Table 5: Linear Voltage Regulators Comparison Table

LM340A fixed voltage regulators are almost obsolete and out of production. The LM7805 fixed voltage regulators are the replacement of LM340s. Due to this fact, LM340A will not be considered for the design. On the other hand, the LM317 adjustable voltage regulator can provide different output voltages based on the components selected. However, for this application, only 5 volts are needed to power the microcontroller chip. Based on this requirement, the LM7805 linear fixed voltage regulator is selected to be compared with a switching voltage regulator that can provide similar or better performance.

To implement the LM7805 package, different designs can be developed based on the applications. The voltage regulator can be either fixed or adjustable. For a fixed LM7805 voltage regulator, the output voltage will always be in the 5V range. However, for an adjustable LM7805 voltage regulator the minimum output voltage will be 5V. Additional protection to these circuits can be provided by adding a diode between the input and output terminals. "Under normal use, Vin > Vout, and the diode is reversed biased. Should Vout become greater than Vin, the diode is forward biased preventing any current flowing into the regulators from its output" *(UCF EEL 4309C Lab Manual).* Two designs implementing the LM7805 will be generated to provide the 5V and 7V regulations required for the controller chip and controller board used in this project design.

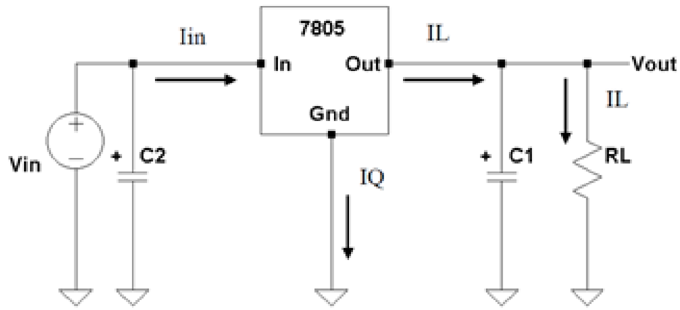


Figure 24: Three Terminal Fixed Linear Voltage Regulator *(Source: UCF EEL 4309C Lab Manual)*

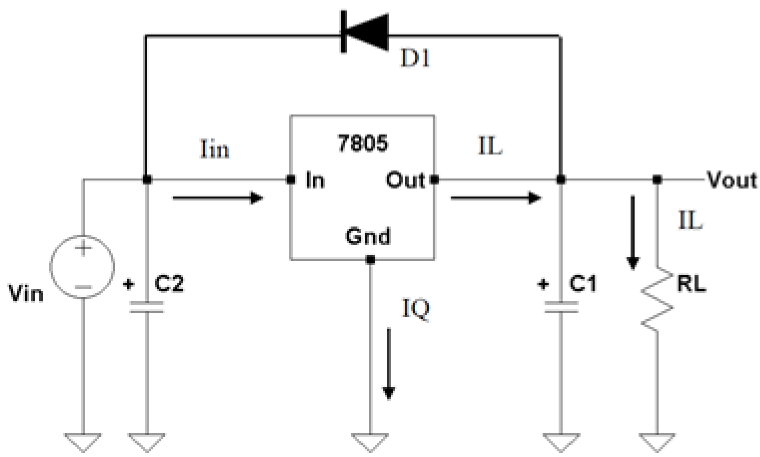


Figure 25: Three Terminal Fixed Linear Voltage Regulator with Protection *(Source: UCF EEL 4309C Lab Manual)*

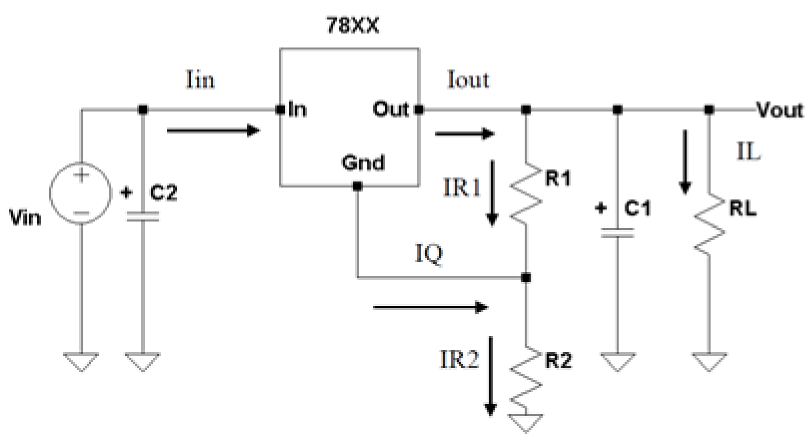


Figure 26: Three Terminal Adjustable Linear Voltage Regulator *(Source: UCF EEL 4309C Lab Manual)*

Besides the LM7805 linear voltage regulator package, a general linear voltage regulator using elements such as resistors, capacitors, a transistor, and an operational amplifier will be designed for testing. This will allow us to compare the behavior of different regulating circuits based on their efficiency, output voltages and currents, among others, to select the best design for the overall design. The following design will be used to implement the 3.3V and 5V linear voltage regulators. From this design, it can be observed that the components placed between the two capacitors is what is contained inside the LM7805 package to regulate different output voltage based on the specifications. This model will be used to perform the computer simulation and design of the circuits since some software do not provide the packages used in these designs. However, the circuits using the packages will be tested on the breadboard to compare their behavior with the computer simulation. It is well known that computer simulation results and breadboard results vary due to environmental factors and the different tolerances of the real components used.

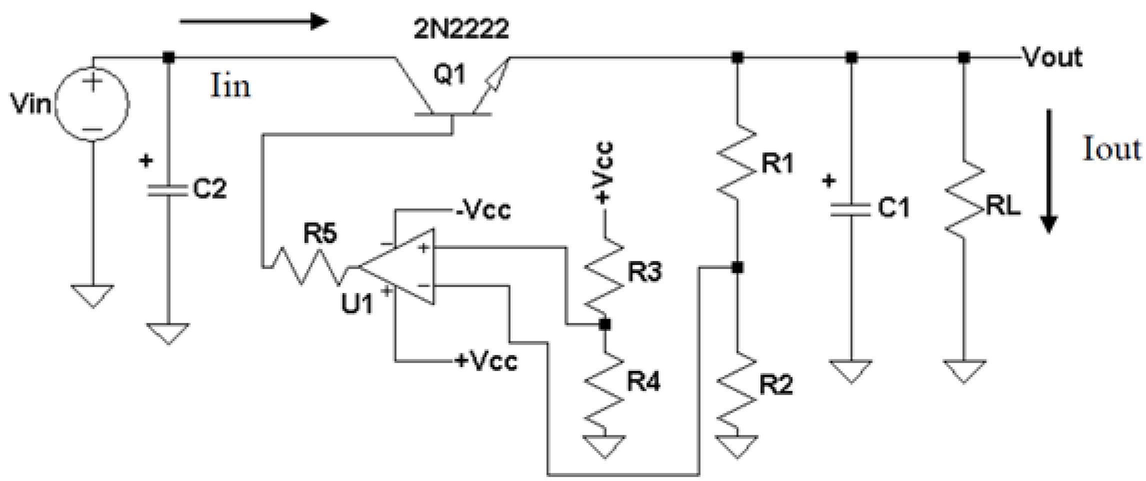


Figure 27: Linear Regulator Example Design *(Source: UCF EEL 4309C Lab Manual)*

The previous linear voltage regulator design can be adjusted to output different voltage levels depending on the selected resistances and capacitances. This design will be adjusted to regulate 12V into 3.3V, 5V, and 7V, which are the required voltages for the components of the systems as well as for the testing environment. The designs for each voltage regulation will be provided on the design section with their respective component values. After each regulator is tested, the final components for the PCB implementation will be selected accordingly with the PCB design requirements as well as the overall project design requirements.

3.2.1.6.2 Switching Voltage Regulator

Switching voltage regulators are most likely to be adjustable; however, they can be implemented to obtain a fixed output voltage. Compared to linear voltage regulators, switching regulators tend to be more efficient. Some of the switching voltage regulators that will be compared are: LM2575, LM2576, and LM2596.

Based on Texas Instruments datasheets for these voltage regulators, the following quantitative measurements correspond to each regulator considered.

Feature	**LM2575**	**LM2576**	**LM2596**
Operating Voltage	4.75V – 40V	4.0V – 40V	4.5V – 40V
Max. Output Current	1.0A	3.0A	3.0A
Operating Temp	-40°C to 125°C	-40°C to 125°C	-65°C to 125°C
Efficiency	77%	77%	80%
Switching Frequency	52 kHz (fixed)	52 kHz (fixed)	150 kHz (fixed)
Unit Price	$2.95	$2.77	$4.77

Table 6: Switching Voltage Regulators Comparison Table

The LM2576 package can be either fixed or adjustable. For the circuits provided on the Texas Instrument LM2576 datasheet, the minimum input voltage is 7V and its maximum is 40V. The fixed design provided is fixed to generate a regulated output voltage of 5V and an output current of 3A. However, an adjustable version is provided which adds two resistors into the design to adjust the output voltage based on the selection of these components. For the project design, three versions will be needed, one to generate an output voltage of 3.3V, another to generate 5V, and another one to generate 7V. Each version will be designed and tested to be compared with the linear voltage regulator and the WEBENCG DC/DC convertor designs for the same outputs.

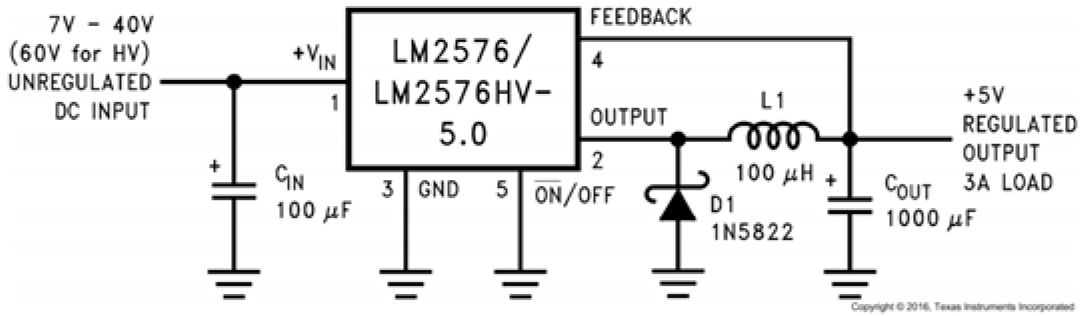


Figure 28: Fixed Switching Voltage Regulator *(Source: Texas Instruments - Literature SNVA559) (Permission Requested)*

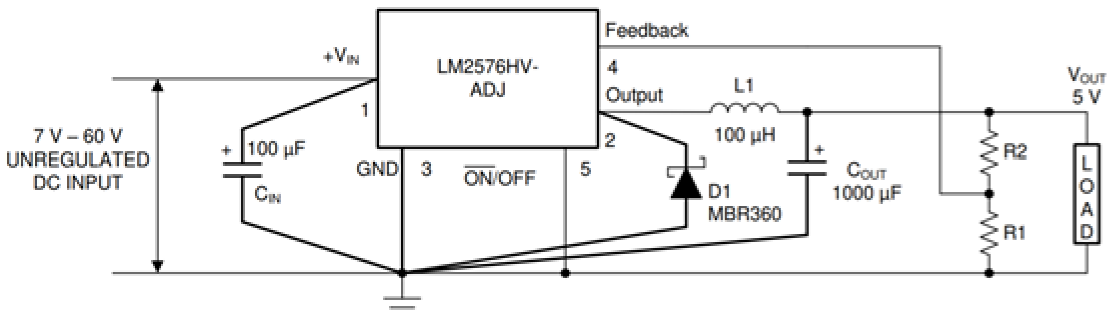


Figure 29: Adjustable Switching Voltage Regulator *(Source: Texas Instruments - Literature SNVA559) (Permission Requested)*

Feature	LM7805	LM2576
Operating Voltage	7.5V – 35V	4.0V – 40V
Max. Output Current	1.5A	3.0A
Output Voltage (typical)	5V	Varies (Fixable to 5V)
Output Options	Fixed	Adjustable
Operating Temp	0°C to 125°C	-40°C to 125°C
Efficiency	Varies (~50%)	77%
Switching Frequency	N/A	52 kHz (fixed)
Unit Price	$1.54	$2.77

Table 7: LM7805 Linear Voltage Regulator versus LM2576 Switching Voltage Regulator

By comparing the LM2576 and LM2596 switching voltage regulators, it can be observed that both of them provide the same maximum output current, operate at a similar voltage range, and are fixable to 5V. However, the LM2596 can operate at even lower temperatures, provide higher efficiency, and have a higher switching frequency.

Although these characteristics seem to be better than the LM2576, the design does not require all of them since they will not be exposed to extremely low temperatures. In addition, the LM2596 cost almost twice as much as the LM2576. So, between these two regulators, the LM2576 satisfies the design requirement specifications. On the other hand, the LM2575 has similar characteristics to that of the LM2576. However, the maximum output current is two amps lower. This could limit the implementation of the design when prototyping. In addition, it is a bit more expensive than the LM2576.

3.2.1.6.3 Final Decision

After comparing different linear and switching voltage regulators, the LM7805 (linear) and LM2576 (switching) were selected to be compared together based on the information collected and discussed above. Once these parts arrive, they will be tested in the breadboard to compare their performance and select the one that provides a better outcome to satisfy the design requirement specifications.

3.2.2 Sensors

In this section, different light, temperature and soil moisture sensors as well as the WiFi modules will be discussed. A final decision will be made based on different characteristics and parameters considered for each sensor and module studied.

3.2.2.1 Light Sensor

Light sensors from two categories discussed in the Background section (photoresistors and photodiodes) are compared to see if they fit the requirements for this project. Two of each chosen light sensor will be needed for the project, as they will be added to sides of the pot and their values will be compared to see which side has the lightest.

3.2.2.1.1 Photoresistors (LDRs)

Photoresistors, or photocells, are essentially light-controlled variable resistors. Based on the guide from Adafruit, they have the following specifications in a voltage divider with a fixed resistor of 10kΩ: resistance range from 600kΩ in a dim to dark area (0.1 lux) to 10kΩ at a brightness of 1000 lux. If the fixed resistor is changed to 1 kΩ, the lux range increases to 10000 lux (Adafruit). The cells detect wavelengths from 400 nm to 600 nm on the electromagnetic spectrum. Wide-ranging power supply up to 100 volt and uses less than 1 mA. The maximum power dissipation is 100 mW. If a supply voltage of 5 volts is used, the power would equal 5mW. There'll be two photocells equally spaced out on the outside of the plant pot. Each cell would be in a voltage divider with a resistor with a set value, which would input its output voltage into the ADC input of the microcontroller. The microcontroller would compare both values to see which side the plant should rotate you for maximum sunlight. Photoresistors are inexpensive ($1 per cell in the US but can be bought in bulk from overseas for $5) and are easy to connect to other passive components such as resistors and capacitors. However, they work best between 0.1 - 10,000 lux. The sensor would frequently be out in sunlight, which can go up to 100,000 lux. This situation could potentially exceed the photoresistor’s maximum power rating and burn it out. In addition, it could be difficult to wire and attach the non-flat photocell to the plant pot neatly.

3.2.2.1.2 SparkFun Ambient Light Sensor w/ Photodiode - VEML6030

The VEML6030 is a digital light sensor with a 16-bit resolution, I2C communication interface, ADC converter, and incorporates a photodiode. Its lux detection ranges from 0-120,000 lux and it is well suited as an ambient light sensor and optical switch. Its spectral response is similar to that of the human eye, which is between 400-700 nm. It requires a supply voltage between 2.5-3.6 V, a stand-by current of 0.5 μA, and a maximum power consumption is 50 mW (VEML6030 datasheet). Furthermore, it is surface mounted onto a SparkFun Qwiic board, which uses JST connectors to attach to a PCB instead of soldering. It cost around $10 ($5 each) for two of these sensors, which would be equally spaced out on the pot's surface. For multiple VEML6030 sensors, the Qwiic board platform provides a multiplexer system. It would connect directly to the microcontroller's I2C pins (SDA1 and SCL1) (SparkFun). Its digital output is more accurate, and its I2C interface makes it easier for the microcontroller to control and communicate with it. It boasts a much wider lux range well-suited to indoor and outdoor environments this plant would be in and only half of the photoresistor's maximum power. However, it costs five times more than the photocell.

3.2.2.1.3 SparkFun Adafruit ALS-PT19 Analog Light Sensor Breakout

The ALS-PT19 is an ambient light sensor with a phototransistor that produces analog output. It has three pins: positive pin, negative pin, and OUT pin. The positive pin should connect to the voltage supply while the negative pin will connect to ground. The OUT PIN would be fed into the ADC pins of the microcontroller. Its operating voltage supply is 2.5 - 5.5 V, its operating temperature range is -40 - 85°C, and its maximum power consumption is 25 mW. It works best for low-power applications such as mobile devices. Its spectrum aligns with that of the human eye which is between 400 to 700 nm. For an incandescent light source (i.e., the sun), a supply of 5 V, and illuminance range from 0 - 10,000 lux, the sensor produces a linear current output of 0 - 5 mA and a linear output voltage range from 0-5 V (ALS PT19 Datasheet). Finally, two of these can be purchased from Adafruit for $5 ($2.50 for each) (Adafruit). This sensor complies with RoHS (Restriction of Hazardous Substances) standards. While less expensive than the VEML6030 and easier to connect to the microcontroller than the LDR, its lux range is just as limited as the LDR for twice the price of it.

3.2.2.1.4 Final Decision

Below is a table comparing the specifications of all three light sensors discussed above. The light sensor chosen for the project is highlighted

	LDR	**VEML6030**	**ALS-PT19**
Output Type	Analog	Digital	Analog
Type of Light Sensor	Photoresistor	Photodiode	Phototransistor
Voltage Supply	0-100V	2.5-3.6 V	2.5 - 5.5 V
Ideal Lux Range	0-10000 lux	0-120000 lux	0-10000 lux
Max Power Consumption	100 mW	50 mW	25 mW
Operating Temperature Range	-30 - 75℃	-25 - 85℃	-40 - 85℃
Price	$0.95	$4.95	$2.50
Communication Interface	ADC	I^2C	ADC
Supplier	Adafruit	SparkFun	Adafruit
Dimensions	4.46 mm x 5 mm x 2.09 mm	25 mm x 25 mm	7.6 mm x 10.6 mm

Table 8: Light Sensor Comparison Table

The final choice for light sensor is the VEML6030. Despite the higher price, its I2C interface, wide lux range, and Qwiic platform make it the perfect choice for this project. The photoresistor would be harder to communicate with the microcontroller and has a limited lux range, and the ALS-PT19 also has a limited lux range.

3.2.2.2 Temperature Sensor

Temperature sensors from the thermistor and digital thermometer ICs categories are compared below.

3.2.2.2.1 TE Connectivity NTC 10k Thermistor 0603

The NTC thermistor from TE Connectivity has an inverse resistance-temperature relationship. This stable, accurate thermistor has a temperature range between -55 - 125℃. The maximum power dissipation is 63 mW ("Negative Temperature Coefficient Chip Thermistors"). It costs $0.876 from DigiKey for a quantity of 10, resulting in a total of $8.76 (DigiKey). It is a 0603 model, which would link to the microcontroller's ADC input and is designed to be surface mounted onto a PCB. While the unit cost is inexpensive and its surface mount design results in a more compact PCB, its analog output would result in reduced accuracy.

3.2.2.2.2 TMP102 Digital Temperature Sensor

The TMP 102 is a digital temperature sensor with the two wire (I2C interface) output with 12-bit resolution (or 0.0625 Celsius). It has a temperature range between -40-125 ℃. It has 1.4-3.6 V supply voltage with a low quiescent current of 10 μA, resulting in low power consumption. It is accurate up to 0.5℃ for the temperature range of -25 - 85 ℃. It would communicate to the microcontroller through an I2C interface using its SDA and SCL pins. Its response time is between 26 and 30 ms for the 1.4 and 3.6 V supply respectively ("Low Power Digital Temp Sensor with SMBus" datasheet). It cost around $5 via SparkFun and would need to be soldered to the PCB (SparkFun). While more than five times more expensive than the thermistor, it offers greater accuracy and communication features.

3.3.2.2.3 Final Decision

Below is a table comparing the specifications of the two temperature sensors discussed above. The temperature sensor chosen for the project is highlighted.

	TE Connectivity NTC 10k Thermistor 0603	**TMP102 Digital Temperature Sensor**
Output Type	Analog	Digital
Voltage Supply	N/A	1.4 V - 3.6 V
Temperature Detection Range	-55 - 125℃	-40 - 125 ℃
Max Power Consumption	63 mW	36 μW
Price per Unit	$0.88	$4.95
Communication Interface	ADC	I^2C
Supplier	Mouser	SparkFun
Dimensions	1.6 mm x 0.8 mm	20 mm x 20 mm

Table 9: Temperature Sensor Comparison Table

The final choice for the temperature sensor is the TMP102 Digital Temperature Sensor. Despite its cost, its low power, I2C interface, and high accuracy make it a good choice.

3.2.2.3 Soil Moisture Sensor - SparkFun Soil Moisture Sensor

The preferred choice for the soil moisture sensor would be the SparkFun Soil Moisture Sensor (Part No. SEN - 13322) at a price of around $6 via SparkFun. It uses two waterproofed probes that lower their resistance in the presence of water and connect to the microcontroller's ADC input using a signal pin connector (SIG) (Al-Mutlaq). Its documentation and straightforward setup make it a clear winner.

3.2.2.4 WiFi Module

The preferred choice for the WiFi Module would be the ESP8266 WiFi Module for $7 via SparkFun. It would enable an Arduino microcontroller to access the Internet via the 802.11 b/g/n protocols, an integrated TCP/IP stack, and WPA/WPA2 security. It requires a 3.0 - 3.6 V supply with an average current of 80 mA and a maximum power of 100 mW, and it connects directly to the microcontroller via TX and RX pins, or the SPI interface (ESP8266 datasheet). Its well-supported documentation and good price make it a good fit for this project.

3.2.3 Mechanical Outputs

In this section, different mechanical output systems will be discussed such as the shading, irrigation and rotation systems.

3.2.3.1 Shading System

The first system that has to be functional in order for this product to be a success, is the shading system. For the shading system, we hope to have the system fully deployable and retractable through the use of a motor. When it came to the selection of the motor, a 12 V DC brushed motor was selected that was able to rotate at a speed of 10 RPM and has a torque of 15Kg*cm. This motor has a very slow speed, which is fine considering as long as the rotational system deploys within a few minutes, it will do its job. Also, another thing that is ideal about this motor selection is the price, this motor is relatively cheap, and the resulting lower cost will be useful in keeping the overall price down for this product. Finally, this motor has a high rated torque at 15Kg*cm. This torque is obtained by having a gear reduction ratio of 1:401, and is useful for having the required torque to overcome the initial moment of inertia of the load. For the system itself, we chose to make the supporting structure out of steel, and the actual shading system itself out of steel and waterproof canvas combo. We hope to create a shading system that will be sturdy, through the use of steel support beams, and light enough to fold up easily with the use of a canvas

3.2.3.2 Irrigation System

When it comes to the irrigation system, Several different parts had to be selected. The first part that came to mind was the pump. In order to provide water to the plant, we needed something that was cheap, and would pump with a pressure that would be strong enough to pump the water. The pump that was found to be perfect for the job, was a cheap 3.6W 12V pump powered by a DC brushed motor. This pump is well within our size requirements, being quite tinny at 1.3” X 1.6” X 2.2” and is able to pump water at an acceptable rate of 240L/H which is about one gallon per a minute. Also, this pump is able to lift liquid to a height of three meters, so it will easily pump the water from our storage container at the base of the project, to the area above where the potted plant is. For the disbursement of the water, a package of drip emitters and 1/4inch tubing will be purchased. The tubing will allow for an appropriate flow of the water, and will allow the user to set up the potted plant so that each area may be evenly doused. The emitters on the other hand, have an adjustable flow rate feature so the watering rate may be adjusted. Once this level is adjusted, the new watering rate can be calculated, and the input can be set by the application to water the plant appropriately.

3.2.3.3 Rotation System

When it comes to establishing the rotational systems for the plant, the size and weight of the pot were the two most important areas to analyze. In order to properly research the mechanical systems of this project, a maximum and minimum pot and plant size had to be constructed. For the minimum pot size, our main limitation comes from the size of the installed irrigation system. With this system, the height of the drip emitters used is 5.1" so in order for that to stability fit within the pot, we recommend a minimum of at least 4 inches. Also, there may be problems with installation if the lower and upper diameter of the pot is less than 5" do to there not being sufficient surface area. For the maximum size, our main concern was mostly the weight and size of the pot as a whole. This product could be altered in the future to accommodate a bigger plant in the future, but in order to keep our outlook reasonable, we decided that the maximum diameter for both the bottom and top of the potted plant should be no more than 9". Also, in order to fit within our weight and height requirements, we recommend that the pot is no taller than 9". The maximum volume of a pot at this max size = V=πr^2 * h = pi * (0.375')^2 * 0. = 0.33 ft^2. A cubic yard of topsoil weighs around 2000 lbs, which means a cubic foot of topsoil weighs 2000/27lbs which is 74.07 lbs. This gives us about 24.444lbs for the weight of our pot and plant. However, estimates for the weight of a cubic yard of soil go up by 50% if the soil is saturated with water. So, because a cubic yard of saturated soil weighs around 3000lbs, plugging this new number into our equation, if the soil was completely saturated and the pot was completely full to the brim, the maximum weight would be (3,000/27) *.33=36.666lbs. Given that it's unlikely that the pot would ever weigh this much due to it being unlikely the soil would be packed in tightly enough and saturated to that extreme, the goal will be to accommodate a pot that weighs 35lbs or less. A rotating metal turntable can be purchased that can accommodate such a weighted pot for a relatively cheap price. In order to make the rotational system, this previously mentioned mechanical turntable will be hooked up to a motor with a belt. The motor chose for this rotational system is a small, 12V brushed DC motor with a rated torque of 15kg*cm. This motor will have more than enough torque to rotate the potted plant system and will be adjusted to rotate the plant at the appropriate speed by altering the size of the tip of the shaft compared to the size of the rotational disk. This will act similarly to how a bike's gears allow the wheel to spin at different speeds depending on the gear ratio. Overall, the rotational system should be relatively straightforward using a motor to turn a disk carrying our potted plant.

3.2.4 Microcontroller

To start the selection process, the type of development board will be discussed. There are numerous manufacturers out there that produce microcontrollers and boards that would work for this project. Many of them had great features that would greatly benefit the project as a whole. However, it was decided that the microcontroller should come from the Arduino family.

Choosing an Arduino development board will provide many benefits. For one, it will allow for programming using Arduino IDE. This is an easy-to-use software that will make the programming process a lot easier. The software is well-known and has been optimized to assure a smooth programming experience. Many others have successfully programmed their microcontroller boards with Arduino IDE and have provided easy to follow tutorials to help teach others. These will be beneficial while trying to perfect the program. (*Introduction to Arduino IDE*)

Choosing the Arduino brand also means that the programmer will have access to the hundreds of Arduino libraries. These libraries are full of many useful functions including communicating with particular sensors, debouncing buttons, and sending data via a Wi-Fi module. These functions will assist with nearly all aspects of this project and will assure solid code for the PCB. (*Libraries*)

Lastly, choosing Arduino helps conquer the compatibility constraint. Arduino has created their own brand on sensors and modules. Using one of their sensors along with their microcontrollers and development boards will assure that all devices will be compatible with one another. If a different brand is chosen, there's a good chance that the device has been designed to be compatible with the well-known Arduino brand. This will greatly help with selecting the appropriate sensors and module for the project. (*Sensors*)

Overall, choosing the Arduino brand will be beneficial in many ways. Even though other manufacturers provide wonderful microcontrollers that would benefit the project, the Arduino brand is the best fit. The Arduino microcontrollers will allow for easier programming, less compatibility issues, and ultimately, a smoother project. Therefore, all microcontrollers and development boards researched and discussed in the sections to follow will be a part of the Arduino family.

3.2.4.1 Arduino Nano

The first development board to be considered is the Arduino Nano which uses the ATmega328 chip. This board operates at a voltage of 5V and consumes 19mA of power. It has 22 I/O with 6 dedicated to PWM. The clock runs at 16MHz and the device has 32KB of flash memory (2KB for the bootloader), 2KB of SRAM, and 1KB of EEPROM. *(Arduino Nano)*

The board is a good option for the project. To start, the voltage and power level are ideal. With a low microcontroller power consumption, the overall power consumption will remain lower and therefore, extend battery life. Having 22 I/O ports is also a great feature as it will allow the microcontroller to communicate with all components of the project at once. The 16MHz clock speed is a great feature as that is plenty fast for the commands to be processed in a timely manner. The fact that it is a part of the Arduino family can be considered ideal. Because of this, the board will have access to hundreds of libraries of useful functions that will help with programming in the prototype stage. This also helps with compatibility. Lie discussed above, Arduino has created numerous sensors and modules that can be used for this project. Using a sensor from the same manufacturer assures that the two devices will be compatible and therefore, will help conquer said restraint. It also can be stated that the lack of a Wi-Fi module on this board is a good thing. Although the Wi-Fi module will provide means for communication between the microcontroller and application, the module will not be present on the PCB and therefore, should not be present on the development board. An external module will be used instead which will provide a more accurate simulation of the PCB. *(Arduino Nano)*

There are also several downsides to the Arduino Nano. For one, the memory is small. Although 32KB of memory is enough to store all data from the sensors, the program itself will have limited space. The size will be acceptable as long as the file is not too large or complex. If complex coding turns out to be necessary, this will cause issues with the board's memory. Other means of storing the code will have to be used which is unnecessary in the prototyping stage. Another downside is the cost. According to the Arduino website, this board can be purchased for $20.70 *(Arduino Nano)*. This is a lot in comparison to the other boards. This will certainly play a factor in the final decision. (Buckley)

3.2.4.2 Arduino Nano Every

The next board to be discussed is the Arduino Nano Every which used the ATMega4809 chip. This board runs at a voltage of 5V and a current of 20mA. It has 20 I/O ports and operates with a clock speed of 20MHz. The microcontroller features 48KB of flash memory, 6KB or SRAM, and 256B of EEPROM. The development board does not include a Wi-Fi module which means that an external module must be used in order to communicate with the application. Finally, according to the Arduino website, this board will cost $20.70. *(Arduino Nano Every)*

The Arduino Every has many promising features. The 5V operating voltage as well as the 20mA of power consumption are all positives. They are low enough to provide an efficient operation. The development board features 20 I/O ports which is enough for the sensors and modules included in this project. Although more I/O ports would allow for the use of more sensors and provide better accuracy, 20 is sufficient for this project. The clock will operate at 20MHz. This rate is slower than that of other microcontrollers but should be sufficient for this project. Another great feature is the amount of memory. This microcontroller will provide 48KB or flash memory which is certainly enough for the data from the sensors as well as the program itself. It is less than that of other microcontrollers, but again, is sufficient for this project. The Arduino Nano Every does not include a Wi-Fi module, but that is beneficial. Like the Arduino Nano, the lack of said module provides a better prototyping experience as the PCB will not include a Wi-Fi module. The lack thereof will help move the prototyping along. This development board has been manufactured by Arduino which allows for use of their function libraries as well as assures compatibility with the sensors. Finally, the cost is much lower than that of the other boards. $10.90 is very reasonable for the device that will be received. *(Arduino Nano Every)*

The Arduino Nano Every has a couple of downsides. For one, the clock will be operating at 20MHz. This is significantly slower than that of other microcontrollers. It would be nice for the system to run at a higher clock speed; however, it is unnecessary for this system. (Everard)

Overall, this development board is a good fit for the project. Although many other devices on the market have better features, the cost is significantly lower. A lower cost will provide a lower production cost which will in turn lower the market price. This particular feature favors the Arduino Nano Every and will greatly influence the final decision.

3.2.4.3 Arduino Nano 33 IOT

The third development board is the Arduino Nano 33 IOT which uses the SAMD21 Cortex®-M0+ 32bit low power ARM MCU for the chip. This microcontroller operates on a voltage of 3.3V and a current of 7umA. The board consists of 14 I/O ports and a clock that runs at 48MHz. The microcontroller has 256KB or flash memory and 32KB of SRAM. Unlike the previous two options, this device does not house and EEPROM. The Arduino Nano 33 IOT has a built-in Wi-Fi module and will cost $18.40 if purchased from the Arduino website. *(Arduino Nano 33 IoT)*

This board has plenty of beneficial features. To start, it runs on 3.3V and 7mA. This is much lower than the previous two which will provide better efficiency and a longer battery life. It also features a clock rate of 48MHz. This is significantly faster than the previous two and will allow data to be processed at a faster rate resulting in a quicker response time of the device. Finally, the Arduino Nano 33 IOT has 256KB of flash memory and 32KB of SRAM. It can store a huge amount of data, but this may not be necessary given that the program itself will not be that large. *(Arduino Nano 33 IoT)*

The development board consists of 14 I/O ports. Although this would be sufficient for many projects, it may not work for this one. This project involves heavy use of sensors and modules – all of which will need to connect to the board through their own port. The more ports readily available, the more sensors can connect to the board and microcontroller which will in turn increase the quality of care received by the plant. Another feature to be discussed is the lack of EEPROM. While two of the other microcontrollers had some form of EEPROM within the chip, this one does not. While this type of memory may not be necessary, it is a bonus feature that certainly can be used if present. The Arduino Nano 33 IOT also features a Wi-Fi module. While the presence of said module would be considered a positive trait in most situations, it is a downside for this project. Like stated above, the Wi-Fi module will not be present on the PCB of the final project so an external source will be used instead. Having direct access to an on-board Wi-Fi module during prototyping may cause problems when switching to the actual PCB stage. *(Arduino Nano 33 IoT)*

The last feature to be discussed is the price. The Arduino Nano 33 IOT costs $18.40 from the Arduino website (Arduino Nano 33 IoT). Although this is a fair price for a nice development board, it is much higher than that of the Arduino Nano Every. This ultimately comes down to debating whether the increase in price is worth the additional features of this particular board. This debate will heavily influence the final choice in the development board.

3.2.4.4 Arduino Nano 33 BLE

The fourth development board to be discussed is the Arduino Nano 33 BLE which features the nRF52480 chip. This board operates on a voltage of 3.3V and consumes 15mA of power. It has 14 I/O ports and a Wi-Fi module built into the board. The device features a large memory consisting of 1MB of flash memory, 256KB of SRAM, and no EEPROM. The clock functions at 64MHz. According to the Arduino website, the entire board will cost $20.20 overall. *(Arduino Nano 33 BLE)*

Like the Arduino Nano 33 IOT, this board runs on 3.3V, but has a power consumption of 15mA. This device will have a better efficiency that others, but not as great as its predecessor. The microcontroller also has the best overall clock rate of 64MHz and features the largest memory of them all. Although both features would be welcome, they are a little higher than what is necessary for this project. An increase in response time or memory size would be great, but they are not needed for this project and are not worth the increase in price. *(Arduino Nano 33 BLE)*

The Arduino Nano 33 BLE also has some negative aspects. For example, the development board only has 14 I/O ports. While this value would be acceptable for the project, it is not desirable as it will limit the number of sensors that could be used for the plant. This microcontroller also does not include any EEPROM. This type of memory certainly is not necessary but would be used if available. Another downside to this development board is the presence of a Wi-Fi module. Including a Wi-Fi module will hinder the board's ability to correctly simulate the PCB. Therefore, the project would benefit from a development board that does not include the module. Finally, this board will cost $20.20 if purchased from the Arduino website. While a price in that range seems reasonable for its features, it is significantly higher than that of the boards. A lower price would greatly benefit the project as a whole, so this particular feature is a major downside to choosing this board. *(Arduino Nano 33 BLE)*

3.2.4.5 MSP430FR6989

The fifth and final microcontroller board is the MSP430FR6989. It was created by Texas Instruments Incorporated and is well known within the electronics community. This board was selected in part because of its significance. The MSP430FR6989 was the device used in the Embedded Systems class here at UCF. All aspects of the developmental board were studied including the numerous components, the datasheet, and the process for programming it. All members of the group have taken the class and therefore are very familiar with the board. For this reason, using the MSP430FR6989 would prove beneficial to the project.

The MSP430FR6989 is run using a MSP430 microcontroller. It runs on 3V and has a power consumption varying from 210 – 1845 µA depending on the frequency of the clock. The board features 83 I/O ports and generally runs on a clock rate of 16 MHz. The device features 128KB or flash memory, 2 KB of SRAM, and no EEPROM. There is no Wi-Fi module present on board. (*MSP430FR6989*) When purchased from the Texas

Instruments Incorporated website, the developmental board will cost $20.00. (*MSP-EXP430FR6989*)

The microcontroller board has numerous benefits. To start, it operates as a voltage or 3V and has a very low power consumption. This is much lower than the other options as it will provide a much more efficient operation and a longer battery and overall product life. It also houses 83 I/O ports. This would be a wonderful addition to the overall project as it would allow for additional sensors and modules to be added to the design. However, doing so would increase the complexity and cost of production which would be a disadvantage. Therefore, the microcontroller boards with less ports would prove as better fits to the overall design. The clock generally runs at 16MHz. Although this value would be sufficient for the board, a higher clock rate would provide faster response time and would be ideal so long as the cost is not affected. The MSP430FR6989 lacks a Wi-Fi module. Like the other researched boards, it is more beneficial if the module is not there. This is because the PCB will not have the board. Therefore, the lack thereof would allow for a more realistic testing environment which will certainly benefit in the prototyping stage. Finally, the MSP430FR6989 would be easy to use. As stated above, the members of this team have all worked with the board at some point and have valuable experience with it. For this reason, programming should be a lot easier than the others. (*MSP430FR6989*)

Another benefit of the board is the software used for programming. Unlike its Arduino counterparts, the MSP430FR6989 is a product of Texas Instruments Incorporated and therefore, can be programmed using different software. One such is Energia IDE. This software is very reliable and easy to use. It also possesses numerous libraries full of ready to use functions that can easily be incorporated which will in turn make the programming easier. This software is incredibly beneficial and will surely influence the final decision. (*Energia*)

Along with its benefits, the MSP430FR6989 also has a few downsides. For one, although the board has 128 KB of flash memory, it only has 2 KB of SRAM. The amount of flash memory remains in the middle of the pack and is a sufficient amount for the project. However, it holds the least amount of SRAM of the bunch. The SRAM is important to the final design and will provide a space for the stored data. Using a microcontroller with a larger amount of storage will allow for more complex code to be utilized as well as increase in the amount of data stored. (*MSP430FR6989*)

Another downside is the price. When purchased from the Texas Instruments Incorporated webize, the board will cost $20.00. Although this amount is not the higher value of the selected few, it is significantly higher than the lowest. A higher components price will of course increase the production cost and will ultimately increase the consumer price. Finding a microcontroller with a lower price is much more ideal as it will lower the production cost, lower the consumer price, and increase the product’s performance on the market. (*MSP-EXP430FR6989*)

Overall, the MSP430FR6989 is a great option for the project. The increase in I/O ports as well as lower operating conditions are very appealing for the final project.

Choosing this developmental board would certainly increase the efficiency as well as the flexibility with the design. It also will provide a more realistic prototyping environment with the lack of the Wi-Fi module. However nice, these parameters are not worth the price. Compared with other boards, these qualities are not as ideal. Although many of these parameters are good, the cost of production plays too big of a role. If another board was chosen with a lower price, as long as the parameters are not significantly less that the MSP430FR6989, then it will most likely be chosen instead.

3.2.4.6 Final Decision

All five development boards were compared based on their power consumption, I/O ports, clock speed, memory, Wi-Fi module presence, and cost. All of these factors were taken into consideration while choosing the board for the project. A comparison of these features has been provided below.

	Arduino Nano	Arduino Nano Every	Arduino Nano 33 IOT	Arduino Nano 33 BLE	MSP430FR 6989
Chip	ATmega328	ATMega48 09	SAMD21 Cortex®-M0+ 32bit low power ARM MCU	nRF5284 0	MSP430
Voltage	5 V	5 V	3.3 V	3.3 V	3 V
Power Consumption	19 mA	20 mA	7 mA	15 mA	210 – 1845 µA
I/O Ports	22 (6 PCM)	20	14	14	83
Clock Rate	16 MHz	20 MHz	48 MHz	64 MHz	16 MHz
Flash Memory	32 KB (2 KB bootloader)	48 KB	256 KB	1 MB	128 KB
SRAM	2 KB	6 KB	32 KB	256 KB	2 KB
EEPROM	1 KB	256 B	None	None	None
Wi-Fi Module	No	No	Yes	Yes	No
Cost	$20.70	$10.90	$18.40	$20.20	$20.00

Table 10: Comparison of Development Boards

For this project, five development boards were considered – Arduino Nano, Arduino Nano Every, Arduino Nano 33 IOT, Arduino Nano 33 BLE, and MSP430FR6989. There were positive and negative aspects of all boards which were used to determine which one would be the fit for the project. Ultimately, it was decided that the Arduino Nano Every should be used.

The Arduino Nano Every was chosen as the best fit for many reasons. For one, the development board uses the ATMega4809 chip. This is a widely used chip that can be purchased for a very low and reasonable price. It is well-known and is capable of handling all that the project will require. The board also was chosen for its I/O ports. The more I/O ports readily available, the more sensors can be used. Having multiple sensors will allow for a more accurate representation of the plant's well-being and will better the quality of care. This will greatly influence the overall quality of the product. Furthermore, this development board does not include a Wi-Fi module. The lack thereof will assure a better experience in the prototyping stages as there will be no module of the PCB. During prototyping, an external Wi-Fi module will be used which is a better representation of the PCB itself. (Jean-Luc Aufranc)

There are several aspects of this board that are not ideal, but are acceptable. For example, the Arduino Nano Every runs on a voltage of 5V and has a power consumption of 20mA (Arduino Nano Every). The Arduino Nano 33 IOT, the Arduino Nano 33 BLE,a nd MSP430FR6989 have lower voltages and power consumptions, however, these do not outweigh the benefits of the chosen board. Other examples include the clock rates and amounts of memory. Again, the Arduino Nano IOT and Arduino Nano BLE have the chosen board beat. However, these still do not outweigh the benefits of the Arduino Nano Every. Furthermore, all specifications are acceptable on the Arduino Nano Every. It would be beneficial to have a faster clock rate of a lower power consumption, however, they are not necessary. The specifications provided by the Arduino Nano Every are sufficient for a successful project. (Jean-Luc Aufranc)

The greatest aspect of the Arduino Nano Every that had the highest influence on the final decision was the price. This development board costs the least out of the four options. Based on the features, this would provide the best overall deal. Although two other boards had better specifications in several areas, they did not outweigh the price of the Arduino Nano Every. For this reason, this board was chosen to be used for prototyping the project. *(Arduino Nano Every)*

3.2.5 Chip

Although an entire development board was used for the prototyping stage, only the chip itself will be used for the final project. This chip will be placed on the PCB and will run the code written in the prototyping stage. It must be capable of receiving data from multiple sensors at once and respond accordingly and in a timely manner. Although time is not of the essence, accuracy is as each command must be sent to the correct piece of equipment in order for the plant to be properly taken care of and the project to be considered successful.

Given that a specific development board has been chosen for the prototyping stage, the chip itself has essentially already been chosen. Because the Arduino Nano Every was chosen as the designated development board, its chip – ATmega4809 will be used for this project *(Arduino Nano Every)*. This chip is well known and features many specifications that will work nicely with this project.

3.2.5.1 I/O Pins

To start, the ATMega4809 features 48 unique pins. These pins vary in functionality from input voltage to providing an I/O port. Based on the pin-out, which has been provided below, the chip features 3 ground pins, 3 input supply pins, 3 pins compatible with the clock, 6 pins for programming and debugging, 6 pins for TWI, 28 pins dedicated to digital functions, and 18 pins for analog functions. Minus the clock itself, most of the data sent and received will be digital. Therefore, the 28 pins dedicated digital pins will greatly benefit the project. It is also beneficial to have several analog pins in case the project calls for an external clock or some other means of analog communication. The pinout for the ATMega4809 has been provided in the appendix and better summarized the use of each of the pins. *(Microchip, 6)*

3.2.5.2 Clocks

For the ATMega4809, there appear to be several options for the oscillators and clocks. First, there are two oscillators – OSC20M and OSCULP32K. OSC20M is a crystal oscillator that can run at two different frequencies – 20MHz or 16MHz. This has a duty cycle of 50% and can start up in 12µs. It has an error rate of ±4%. The OSCULP23K runs at a frequency of 32.768kHz. It has a duty cycle of 50% and a start-up time of 250µs. This oscillator runs with an error rate of ±20%. Both oscillators can be used for the project depending on the requirements at the time. *(Microchip, 12)*

There are two options for the microcontroller's clock – XOSC32K or an external clock. XOSC32K typically runs at a frequency of 32.768KHz. This of course can be changed if needed. The clock has a start-up time of 300ms. This is a long time but is acceptable for the project. An external clock may also be used instead. The frequency must range from a minimum frequency of 0Hz to, depending on the value of $V\text{-}_{DD}$, a maximum value of 5, 10, or 20MHz. This close must have a maximum rise/fall time, depending on the value of V_{DD}, 40, 20, 0r 10ns. The change in period between cycles must always have a maximum value of 20%. *(Microchip, 12)*

For the project, it is likely that the internal clock will be used for all operations. This is because it will provide sufficient timing and accuracy for a successful outcome. Although the option of an external clock is nice to have and will be considered if the internal clock proves to be unreliable.

3.2.5.3 Power Consumption

As with any device, power consumption is a key feature. Most devices strive to consume as little power as possible in order to keep the battery life and efficiency high. This project will be no exception. With the microcontroller and chip already picked out, it is a little challenging to try to adjust its power consumption. According to the datasheet, however, it is possible by selecting different certain devices over others and changing the value of V_{DD}.

According to the datasheet, both the 20MHz clock and the 32.768kHz clock have different levels of power consumption. If V_{DD} is set to 5V and the clock is active, the 20MHz clock will typically consume 8.5mA while the 32.768kHz clock will consume 16.4 µA. The faster clock uses significantly more power than the slower one which makes sense as running the clock at a faster speed should require more power. The same pattern follows when the clocks remain idle. With V_{DD} = 5V, the 20MHz clock consumes 2.8mA while the 32.768kHz clock consumes 5.6µA. This pattern makes it clear that using a clock at a slower speed will lead to a higher power consumption. *(Microchip, 31)*

Another method for reducing the power consumption is by dividing the clock. Dividing the clock will allow for a slower clock rate which will in turn reduce the amount of power consumed. The clock can only be divided by factors of 2 which will cause the power to be reduced by factors of 2 as well. This pattern can be seen on the datasheet. When V_{DD} = 5V and the clock is active, the 20MHz clock will consume 8.5mA. When the clock is divided by 2, it will run at a frequency of 10MHz and will consume 4.3mA. Dividing the clock again will result in a frequency of 5MHz and a power consumption of 2.2mA. This pattern holds true for an idle clock. A 20MHz frequency will consume 2.8mA, 10MHz will consume 1.4 mA, and 5MHz will consume 0.7mA. If time is not of the essence, dividing the clock is a great way to assure low power consumption and high frequency. *(Microchip, 31)*

3.2.5.4 Timers

Most microcontrollers have built-in timers. These use one of the internal clocks to count the amount of time that passes by. This is a simple function to implement, so it is common for the device to have multiple timers. These timers can be implemented in many ways. For this project, multiple timers will be used for various tasks such as rotation time and periods between watering. Doing so will ensure that the plant receives the proper care as determined by the microcontroller.

According to the datasheet, there are six built-in timers within this chip – one Type A and five Type Bs. Both types have a 16-bit count and run on1MHz. However, Type A consumes 13µA or power while Type B consumes 7.4µA. This means that utilizing the Type B timers will provide lower power consumption and a higher overall efficiency. The Type A timer can be programmed using the term “TA0” while the various Type B timers are called with the term “TCBn” where n is the timer number. *(Microchip, 13)*

It is also important to have multiple timers. Due to the nature of this project, many intervals will need to be timed during operation. Although several timers can be reused for similar functions, many cannot. Therefore, the use of multiple timers is crucial to the success of this project. Depending on the number of features included, this project may require more than the six timers provided. In that case, an external timer – potentially with an additional external clock – will be added to the board so that all functions are a success.

3.2.5.5 Communication

According to the datasheet, two types of communication can be implemented with this chip – USART and SPI. Both protocols are popular among microcontrollers and can be easily implemented in this project.

The first type of communication protocol is USART or Universal Synchronous Asynchronous Receiver Transmitter. This form is similar to UART, however it can utilize synchronous or asynchronous clocks while its counterpart only runs on asynchronous. With this protocol, data is sent from one device's transmitter to the other's receiver over a bus. Typically, this protocol is implemented without the use of a clock. Instead, it uses the start and stop bits along with the baud rate to determine the sampling times. However, USART can be implemented with a clock which will help assure the data is received correctly. The lack of clock means that the devices must send an acknowledgement after receiving a message. One upside to this protocol is the number of wires. If used asynchronously, USART only requires two connections between devices – one for each direction of message transfer. If the synchronous option is used, the protocol will require an additional wire for the clock. Given the number of devices that will be communicating with the microcontroller at once, this will be an important factor in the ultimate decision. USART is a great candidate for the communication protocol for this project as it will assure that each device receives its appropriate data in a timely manner and frees up a clock for another function. *(Basics of UART)*

SPI is the second type of communication protocol compatible with the ATMega4809. SPI stands for Serial Peripheral Interface and is another common form of transferring data. SPI operates with synchronous clocks which means that all devices are running on a clock with the same frequency. This assures that the receiver knows exactly when to sample the signal in order to correctly read the message. *(Basics of SPI)* This method required 5 connections between the devices. With the number of components that will be utilized in this project, the amount of connections will be much higher than that of USART. Due to the synchronous nature of this form of communication, acknowledgements are not required after data is sent. This will result in a higher efficiency of the code, but also means that the master will continuously send data and remain unaware of whether or not it was received. This protocol is a great option for the project as it can easily be implemented for the many components required for this project. *(Microchip, 31)*

I2C is the third and final form of communication readily available. This type is synchronous which means that all devices within the network run on the same clock. Using a synchronous form of communication assures that all devices know exactly when to send the data so that the receiving end can correctly sample the signal to find its values. The system works with a designated master and slave. The master will send commands to the slave who will in turn respond over the same full-duplex wire. The system requires two wires – one for the data transfer which is called SDA and the other, called SCL, is used for the clock. The master can have as many devices attached as long as they are capable of said communication. I2C is also capable of incorporating multiple masters. This would be beneficial if the project gets too complex and requires the use of a second CPU. (Campbell)

There are few downsides to this form of communication. For one, the data frame size is limited to 8 bits. This is annoying as the master will have to frequently readdress the device that it is trying to talk to when sending a long message. The system could also fail if both masters try to send a message at the same time. However, there are protocols in place to assure that one master will back off and allow the other to finish before attempting to retransmit. (Campbell)

One aspect that should be noted is the fact that the datasheet does not list I2C as a viable option for communication. It is rather odd given that this is a well-known protocol and the other two have been mentioned at least once in the datasheet. Despite this small error, it appears that the chip is still capable of utilizing I2C. This is because on the block diagram of the microcontroller itself, there is mention of SDA and SCL for both the master and slave roles. These would not be included on the block diagram if I2C could not be utilized. Therefore, it is fair to assume that the microcontroller is capable of performing I2C and can be used for the project. *(Microchip, 5)*

As stated above, this project will require communication between the chip itself and numerous components on the PCB. This means that the choice of protocol is important as it must be able to handle a large number of connections as well as provide efficient means for sending data. For this reason, I2C will be used for this project. For one, I2C can be implemented with a clock. The ability to utilize multiple masters also played a large role. This will allow for easy integration of multiple CPUs into the system if the project requires it to be done. This provides stability and assures that all components will know exactly when to sample the signal. It also requires fewer wires which will save space on the PCB. The last factor that ultimately drove the final decision is the compatibility with the sensors. The sensors chosen for this project have been designed to use I2C. Given that the microcontroller must be able to communicate with said sensors, I2C was the ultimate decision for communication protocol. *(Microchip, 5)*

3.2.6 Application Design Software

Several functions will be implemented in this app. First and most importantly, there must be a way for the user to insert the data. Ideally, there will be a drop-down list with pre-inserted care routines. The list will include the names of many commonly grown plants and, when selected, will send the correct watering and sunlight patterns to the microcontroller for processing. If the desired plant is not included on the list, there should be a way for the user to insert data manually. This will involve two text boxes – one for the amount of water and one for sunlight. After the data has been inserted, the user will press the submit button and all data will be sent to the microcontroller for processing.

Another function that will be implemented is a method for the user to manually control the various systems within the project including the irrigation, rotational, and shading systems. These will be implemented using buttons. When the button is pressed and depending on the current state, the system will be activated or deactivated. For example, if the user wants the plant to be watered right away, they can open the app and press the water button. This will cause the microcontroller to send a signal to the irrigation system requesting it to send water into the plant. This will continue until the user presses the button a second time which will cause the irrigation to stop. The same will occur for the other systems. The purpose of this function is to provide a method for the user to manually control the device. This will be useful during the final showcase stage of this project as it will provide a method for proving that the project was successfully implemented.

It is also important that this application is user friendly. This is because the target audience for the project consists of the average person who will not necessarily be good with technology Therefore, the application must be easy for anyone to maneuver. This particular requirement can be met if the required functions are easy to find and include as few steps as possible. This will be implemented by condensing the app. There will be few pages for the user to look through. Everything will be presented in the same location so that it will be easy for the user to find what they are looking for. Also, the processes will be as short as possible. For example, inserting data regarding the plant will require two steps = inserting the values in the text box and pressing submit. If the process was longer, then it would be easier for the user to make a mistake. A simpler design allows for a smoother user experience and less room for error.

When designing an application, there are two types of devices that apps could be written for – Apple or Android. Apple phones were created solely by Apple and run on the iOS operating system. Apple created their own programming language which is used to program all of their devices. This means that designing an app for an Apple device would involve utilizing their language. Due to the exclusivity of said language, designing for an Apple phone means that the app can only be used on an Apple phone which in turn means that the app will not be compatible with phones from other companies. Because this project should be accessible to anyone, it would be beneficial to use a programming language that is compatible with the majority of phones on the market.

The second choice of phone is Android. Android devices run on an operating system called Android which are typically coded using Java or C. These are widely known languages which would make the coding process easier. This also indicates a lack of exclusivity that is present with Apple® devices. The Android name is used widely throughout the market which means the application will be much more accessible that one written for Apple. Although the functionality of Apple® devices is more well-known by the programmers for this project, the use of Android devices would lead to a better outcome of the project as the programming process will be significantly easier and the app will be more accessible by the general public.

Applications - regardless of the device they are designed for – must be programmed like everything else. Due to their popularity, a tremendous amount of software has been written to make it easier for programmers to successfully develop their apps. There is a wide spectrum of software on the market. Some have been written exclusively for Apple products while others can be used for any type of device. Some provide more features while others cost more to use. For this project, the software should be easy to use and cost as little as possible. Ideally, the software would allow for designing the same application for Apple and Android. However, that is unlikely due to exclusivity of the Apple brand. As long as the software allows for a successful and functional application, it is a candidate for this project.

3.2.6.1 Power Apps

The first piece of software is Power Apps. This software was written by Microsoft and allows for an easy designing process. There are two versions of this software – Plan1 and Plan 2. Plan 1 costs $10 per month and provides all basic functions for designing an app. It is sufficient for simple applications that are not very complex. Plan 2 costs $40 per month and unlocks more design tools. This plan allows for a much more complex design and can be used for even the toughest of creations. Because this software belongs to Microsoft, a subscription to Microsoft 365 will allow one to use Power Apps. This would be beneficial if other Microsoft software is used for this project. *(PowerApps Pricing)*

One benefit of PowerApps is its design. The software was designed to be incredibly user-friendly. It is very easy to navigate between functions and find exactly what one is looking for. This is an important feature of the chosen software. Designing an application can already be challenging enough and a complex piece of software only makes it worse. PowerApps was designed in a simple way which will allow for an easier programming experience. (Marvin and Watts)

Another feature of PowerApps that could be useful is the templates. PowerApps has a wide variety of predesigned templates from the planners to financial calculators. Using a template will cut the amount of time required for designing tremendously. The template will provide most of the features required for the application. All that must be done from there are minor tweaks to assure the design fits the needs of the project. If none of templates fit this project, a brand-new design can be created from scratch. This will allow the designed full control over all aspects of the application. Although the templates will not necessarily be used for this project, they may prove handy as they will provide solid ideas of what a well-designed application should look like. (Marvin and Watts)

PowerApps comes with a feature called App Checker. This software allows the user to periodically check the design for errors. This is a great feature as small mistakes within the code can be hard to find and lead to large issues. App Checker will allow the user to easily identify problems within their design and fix them in a timely manner. This will greatly reduce the time required for designing the application as it will significantly eliminate the time required for checking for bugs. (Marvin and Watts)

PowerApps has many great features, but also has a few downsides. For one, although the software is rather easy to use, it can be slightly overwhelming at first. Because everything is out in the open, it does not require many steps to get to a desired function. However, the high volume of functions on both sidebars can make the first glance at the software slightly overwhelming. This makes the software initially look less desirable. However, with a little practice and the help from various tutorials, PowerApps can be learning relatively quickly. (Marvin and Watts)

Another downside is the load time. PowerApps takes a bit longer to load than its counterparts. This means that uploading data for the app or creating new functions will take a bit longer than desired. However, this particular trait has little effect on the overall decision. Although it can be annoying to wait around longer, the speed is not vital to the success of this project. PowerApps has other promising features that are more important to the final decision. (Marvin and Watts)

Overall, PowerApps is a good option for the application software. It is very reliant and has many features that are desirable. Because the software was created by Microsoft, which is a well-known company, it is safe to assume that the software will be incredibly reliable and will have all features required for designing a respectable app.

3.2.6.2 XCode 12

The next software is XCode 12. This software was created by Apple. It is a well-known program that was created strictly for designed apps for iOS, the operating system used by all Apple products. Any application designed with this software can be easily modified to fit all forms of Apple products. XCode 12 is free, but the user must join Apple's developer program which will cost $99 per year. This is much higher than the price of the previous software but will allow the programmer access to all that Apple has to offer. (*How Much*)

Although Apple products are programmed using the language Swift, this language does not need to be used with XCode 12. In fact, the software supports the use of many other languages including C and Java. This provides a major advantage for the application design. Because Swift is solely used for Apple, it is not well-known like some other languages. Having the ability to use C or Java will lessen the learning curve required for using this software and make for a much smoother designing process. (*Xcode: Updates*)

XCode 12 offers numerous editing features that would be beneficial to the overall design. When using this software, both the code and a preview of the outcome can be seen simultaneously. XCode 12 offers a neat feature that will allow the user to edit pieces of the application as ease. The code will automatically group the features of the app into various sections. For example, a large box of text will be considered one until while the photo next to it would be another. If the user wants to slightly darken the image, all they need to do is drag the darkening effect to the image. The software will instantly edit the photo as requested and update the code to match. This wonderful feature assures that the user is able to successfully edit their application without causing error in the code. If the user would prefer to manually edit the code, they can do so. They can type whatever they wish in the program and XCode 12 will automatically update the app preview accordingly. This produces quick results which will ultimately allow the user to constantly check their code as the programming commences. This is a huge time saver and again, makes the app designing process significantly easier. (Advent)

Apple has provided numerous libraries full of functions that can help with programming. Because XCode 12 was designed by the same company as the phones that will be used, all of the quirks of said phone will be known. Apple is aware of features that the app developed may want and has created functions to accommodate them. For example, iPhones have the time, service, and battery status on the top of their home screens in what is known as the status bar. While some applications benefit from the presence of this status bar, others do not. Therefore, Apple has created a function that will allow the designer to add or remove the status bar from their application as they please. Using said function with the editing tool stated above will allow the user to easily edit their app and allow their code being adjusted along the way. This is another incredibly beneficial editing tool that will be greatly appreciated when designing the application. (Advent)

Despite the numerous benefits of XCode 12, there are a few downsides. For example, XCode 12 is a product of Apple and therefore, can only be used for designing applications for Apple products. Although it is very easy to translate the code between the operating systems for iPhones, iPads, and Macs, XCode 12 cannot use the data to create an application for an Android. This means that another design software must be used for creating an application for any other type of device. (*Xcode*)

Another downside is the software requirements. XCode 12 can only be run on an Apple device. In order to use their software, one must be in possession of a Mac computer as the software was written specifically for macOS. This is problematic as the programmer for the project does not have easy access to a Mac and would need to purchase one. Doing so will greatly increase the cost of prototyping which could potentially push the project outside of the budget boundaries. This flaw can be avoided with the use of another piece of software. (*Xcode*)

XCode 12 provides a wonderful tool for designing applications. It is very easy to use, allows for previews on a wide variety of devices, and allows for a much smoother designing process. It has plenty of great features that would limit the number of errors within the code. However, the price of XCode 12 is much larger than that of its competitors. Although the price of the software alone is a mere $99 a month, a Mac computer must be purchased which will increase the overall cost by a tremendous amount. Therefore, XCode 12 is not an ideal choice for this project.

3.2.6.3 Adobe XD

The third software is Adobe XD. This software was developed by Adobe and can be used for designing mobile applications. The simplest software package will cost $9.99 per month while the more complex version costs $52.99 per month. (*XD Individual*

Pricing) Adobe XD can be used for both Apple and Android applications providing the user a method for easily switching between the two. It is relatively new to the market, but has amazing features to assist with designing the app. (*Learn Adobe XD*)

Adobe XD was designed to involve as little coding in the design process as possible. In fact, the code itself is not visible within the main window. All the user has to do to edit their app is click on whatever they want to change and use one of the tools provided. For example, an image can easily be added to the application by adding a slot to the design and dragging the image directly to it. From there, the user can use the editing tools to change to image to fit the full design of the application. Because this product was designed by Adobe, it is compatible with other Adobe products. This means that an image designed in Photoshop can easily be added to the application. This will come in handy if a logo is designed for the project. (*Learn Adobe XD*)

Adobe XD can be run in two modes – design and prototype. Design mode allows the user to edit each individual page within the app. For this project, there will be a welcome screen, a page for submitting data to the microcontroller, and a page that allows the user to manually control each system. In design mode, the user will be able to create each individual page separately. The software knows that all pages belong to the same project so by default, a change to the background color or font on one page will automatically change it on all of them. This feature assures consistency throughout the entire design unless otherwise specified. Design mode is where the text boxes and buttons will be added to each individual page. If an image should be used, it will be placed in this mode as well. The Adobe XD windows lines up all pages within the application side-by-side so that the designer can see them all at once and assure that they are consistent with one another. This feature is an added bonus as it was not present in any of the software listed above. (*Learn Adobe XD*)

Prototype mode allows the user the designer to add functionality to the application. This is where the designer links buttons to each of the pages and edit the functionality of the elements. The project's application will have several buttons on the home screen which will lead the user to the other two pages. In prototype mode, the designer will be able to make those connections by simply dragging an arrow from one page to the other. They also feature back buttons which will function the same way. Adobe XD also allows the designer to add transitions between pages. This leads to a more professional looking application that would be seen in a real app store. (*Learn Adobe XD*)

Another important feature of this software is the ability to add overlays. Overlays are important as the use of a keyboard is vital to the success of the project. The user must be able to add new data about the plant to the microcontroller. Of course, this cannot be done without a keyboard. Adobe XD allows for easy placement of the overlay. Simply run the program in prototype mode and add a keyboard to the design. This will assure that when the user clicks on the textbox will automatically pop up. All features stated above will make the designing process a lot easier. (*Learn Adobe XD*)

Another benefit is the presence of tutorials. Like all of their products, Adobe has created numerous tutorials for using Adobe XD. They have everything from adding new pages to changing the background color to a specific shade. These are free tutorials that can be accessed by anyone at any time. This is great upside as it will help with the learning curve. The designer of the application has no experience with Adobe XD and will have to research before using it. The provided tutorials will greatly help with learning the software and assure that few mistakes will be made while designing. (*Pros and Cons*)

One downside to Adobe XD is the lack of code. Although the designing process has been made significantly easier, the lack of code can be a bit alarming. As the designer, it is of course desirable to be able to see the code you are working on. Even if the design process has been made easier, they of course would want to see the code so they are fully aware of what is going on and can make changes that the software is unable to assist with. However, for this project, this is a minor inconvenience. Due to the simplicity of the application, there will be no complex functions added to the code. Adobe XD provides all that is needed to successfully implement the requirements. Therefore, the lack of code will not have much impact on the final decision. (*Learn Adobe XD*)

Another downside involves the preview mode. Adobe XD allows for a phenomenal previewing more for Apple products. An application designed for an iPhone can easily be viewed on an iPhone by simply uploading the design to Creative Cloud and then uploading it on the phone. The application will appear just as it did while it was being designed and, if everything went well, will perform flawlessly. However, this is not the case for Android phones. Designs for Android cannot be previewed on an Android device in this way. Instead, the user can only preview the app within the browser itself. If the designer wants to view the application on an actual Android phone, they will have to upload the completed application to the app store and then download it on their device. This method is less than ideal as viewing the application on its desired output device would greatly benefit the designing process. (*Learn Adobe XD*)

All applications need a place for storing their data used during operation. Adobe XD was designed by Adobe who, unlike the other major corporations, does not have a piece of software that can be used for data storage. Therefore, a product from another company must be used. One type is Google Sheets. Like the name implies, this software was designed by Google. It follows a spreadsheet format, including an unlimited number of rows and columns of boxes that can be used for storing data. All data can be sent to the document when initially received and then pulled back to the application for use at a later time. This is a great way for the data to be stored without utilizing storage from another device. (*Google Sheets*)

One important factor in favor of Google Sheets is its compatibility with Adobe. Given that this application will utilize Adobe XD, it is important that they are compatible with one another. Otherwise, the two will not be able to interact. Google Sheets can be added to the software using a plugin. This will allow the software to be added to Arduino XD and for data to be shared with the application. This is an important step to assure that the application has all data required to be successfully implemented in the project. (Chen)

Overall, Adobe XD is an excellent choice for application design software. It provided numerous features that will greatly benefit the application. Not only can the application be designed for both Apple and Android, but also the process is incredibly smooth. Adobe XD provides a ton of features that make adding elements to the application a breeze. It also does a very good job of assuring that all pages of the app remain consistent with one another. Although there are a couple of limitations with previewing, Adobe XD has tremendous value for its price and will be greatly considered in the final decision of the application design software.

3.2.6.4 Final Decision

It was ultimately decided that Adobe XD will be used for designing the application. Although PowerApps and XCode 12 were great candidates and would have provided exceptional apps for the project, Adobe XD was chosen as the best fit.

The first and most influential feature of Adobe XD is its ability to write for both Apple and Android. One of the primary decisions in the app designing process was which type of phone to use. This decision was only made because much of the design software readily available on the market can only be used for Apple or Android – not both. The software that can be used for both costs much more than its single device counterparts. Adobe XD has the ability to write for both while keeping its cost at a minimum. This will allow the application to be available on both the Apple and Android markets. This will greatly increase the accessibility of the product to its customers and increase the potential audience as they will not be required to have one phone or the other to correctly utilize all features. (*Learn Adobe XD*)

Adobe XD also has a very easy to use format. The program was clearly written to make the designing process as easy as possible. Instead of viewing the code and periodically running a simulation to see the outcome, Adobe XD allows for the app to be designed strictly in the preview stage. The designer is able to make all changes to the app all from that preview stage and without writing a single line of code. The lack of code will assure that coding errors do not occur which will greatly speed up the designing process. It will also assure that the app is designed exactly as the user intended. There is no room for error due to lack of coding knowledge. Instead, everything can be designed using the functions provided within the software itself. (*Learn Adobe XD*)

Another benefit of the format is the use of design and prototype modes. These modes allow for a much smoother designing process as they allow for both sides of the designing process to run smoothly. Design mode is very easy to use and assures that the application looks consistent throughout. Prototype mode allows for all pages to be viewed at once and makes connecting them to one another very simple. This is a feature that was not seen in either PowerApps or XCode 12 and certainly pushed Adobe XD to the top. It will provide a very smooth design process. (*Learn Adobe XD*)

The previewing mode is another ideal feature within Adobe XD. Although previewing the app within the software itself is very realistic and should be sufficient, having the ability to view the app on a phone is very beneficial. This will allow the functionality to be tested in real time on a real device. This feature was not offered by PowerApps or XCode 12. Although the ability to test the application of a real device is not necessary, it is helpful and will benefit the project greatly. (*Learn Adobe XD*)

Finally, Adobe XD was chosen for its price. The basic package will cost $9.99 per month. This is very reasonable given the features provided as well as in comparison to PowerApps and XCode 12. Adobe XD has numerous features to make the app designing process a lot easier. These features can be priced much higher than they have been. When comparing with the other two design software, this was the best deal. PowerApps has the same price as Adobe XD, but is less easy to use. XCode 12 is slightly cheaper with an annual fee of $99 which comes down $8.25 per month, but also will involve the purchase of a brand new computer in order to run the software. It is much easier and more cost efficient to stick with Adobe XD. (*XD Individual Pricing*)

It should be noted that computers at the UCF library come equipped with Adobe Creative Cloud. This allows access to all Adobe products for free – including Adobe XD. As long as the application is designed from one of these computers or a personal computer is connected to them through UCF Apps, access to this software will essentially have no cost. (*Software*).

	PowerApps	XCode12	Adobe XD
Cost	$10/month $40/month	$99/year	$0
Company	Microsoft	Apple	Adobe
Phones Written For	Apple and Android	Apple	Apple and Android
Easy to Learn	Harder	Easier	Easy
Ability to See Code	No	Yes	No
Computer Requirements	None	Mac	None

Table 11: Comparison of Application Software

4.0 Design Constraints and Standards

This section introduced different realistic design constraints and standards related to the project design. Constraints such as economic, time, environmental, social, political, ethical, health, safety, manufacturability, and sustainability constraints will be discussed in this section.

4.1 Realistic Design Constraints

There are different realistic design constraints related to the project design. As mentioned before, this section will introduce and discuss these constraints based on different categorizations. The constraints to be explained are economic, time, environmental, social, political, ethical, health, safety, manufacturability, and sustainability constraints

4.1.1 Economic and Time Constraints

When completing this design project there are several economic and timing constraints that altered our progress and scope of the project. For one, each student preferred that the project cost them no more than $500, so our total cost was limited at a maximum of $2000. Also, each student has a mixture of other classes and workloads to deal with, and therefore, there have been some timing constraints on when we have been able to meet together as a group. Each student therefore can only be expected to work on the project a few hours a week, and therefore, there is a limited amount of time that will be spent on the overall design of the project. In all, there are limitations on what our group can do that affect the overall outcome of the project and limit our overall complexity.

4.1.2 Environmental Constraints

Environmental constraints demonstrate how much resources this project consumes and how reusable or recyclable the product is. These qualities include solar panel energy generation, battery consumption and waste, durability of devices to inclement weather, and the corrosion of moisture sensors. These characteristics are discussed in the paragraphs below.

Solar panel energy generation is limited by length of the day and the presence of sunlight in a day. The average time a solar panel can collect energy is 4.4 hours. While one solar panel should be sufficient in recharging batteries, it would be wise to include non-rechargeable batteries as a backup as well.

All mechanical and electrical systems depend on the battery supply. In this case, portable rechargeable and non-rechargeable DC batteries make up the battery supply. Rechargeable batterie's energy can be restored (however, that restored energy is limited by the amount of sunlight the solar panel collects. As the batteries lose energy their output voltage also decreases. Thankfully the voltage regulator can produce a steady output from batteries to the mechanical and electrical systems as long as the batteries remain above a certain threshold voltage.

Rechargeable batteries do eventually wear out due to their eventual lack of chemicals to carry out reverse reactions. Thus, that brings up the issue of battery disposal. The project uses lithium-ion batteries, which are hazardous materials in transport according to the UN/DOT 38.3 battery standard. The metals in the batteries may leak and cause fires. Thus, lithium-ion batteries should be disposed of at an electronic waste recycling center instead of in regular trash (Bolt).

This project is geared toward subtropical climates like Florida and will be outside exposed to unpleasant weather. While the shading system can shield it from extreme heat or light rain, the systems would still need to be able to handle high temperatures and water splashing on them. For high temperatures, the majority of the electrical and mechanical equipment can handle up to 60°C (140°F), which is more than suitable for even the hottest areas on Earth. For splashing water, the light sensors and PCB can be covered in a thin plastic wrap or clear plastic container attached to the plant stand.

Finally, moisture sensors corrode due to strong conduction in water. The more current that runs through it, the faster it corrodes. Its life can be extended by powering it on as little as possible (turning it on via the digital pin to get a reading then immediately turning it off) (Al-Mutlaq).

4.1.3 Social Constraints

Social constraints deal with the public's view of the product. This can include a wide variety of factors including the way the product looks to its ease of use. The social constraints can play a large role in the public's acceptance of the product and its overall performance on the market. If the general public does not like the product, they are more inclined to find an alternative solution to their desires. This means that the product will not do well in sales and will be quick to leave the market. If the public thinks highly of the product, they will be more inclined to purchase it and recommend it to others. This will lead to higher sales margins and overall better performance on the market. (*Constraints on Construction Projects*)

Another interesting aspect of social constraints is the fact that, unlike some of the others, social constraints are constantly changing. The general public is constantly changing its preference. For example, the general public may be favoring a certain type of phone over the others. This allows said phone to have a dramatic increase in sales, increasing its performance on the market and is one track to become the most popular phone in the country. With time, the public's opinion will change. If their current favorite does not update and upgrade to match the everchanging desires of the public, they will stop buying it and move on to a new phone. Therefore, the company must be constantly surveying the opinions of the public to assure they have a good understanding of their preferences and use that to update their technology accordingly.

Another thing that is specific to the technology field is the rapidly changing market. All manufacturers within this field are constantly trying to improve their products in order to outdo their competitors. This means changing things like camera quality or amount of storage readily available for the user. This is a vital piece of information for anyone trying to be successful in this line of business. If a manufacturer chooses not to upgrade their products with their competitors, they will fall behind. Instead of buying their products, they will find new manufacturers with better products. This means that manufacturers within the technology field must always try to update their products to match those of their competitors to assure that they remain favorable in the eyes of the general public.

For this particular project, there are several social constraints that should be taken into consideration. The first one is that the product must remain affordable by assuring that the market price stays as low as it can. It is well known in all lines of business that it takes money to design and implement a new product. From labor fees, costs of parts, and the necessary advertising, the price of producing a new product adds up relatively quickly. The more money that is put into the product, the better the quality and the higher chance the general public will approve causing the product to do well in sales. Therefore, it seems that spending more money in order to use the best parts is ideal. However, this is not the case. When more money is spent on a product, the cost of production goes up. In order to make a profitable sale, the market price must go up too. This will make the product less favorable in the eyes of the public as they will not want to pay more money for it. This causes sales to go down and potential monetary issues later on. This is where the social constraint is born. The ultimate goal is to keep the market price as low as possible while assuring the highest profit. From a manufacturing point of view, this means using the best parts one can find while spending as little money as possible to assure that the consumers will pay a lower price. The manufacturer must find a good balance between the quality of parts and the price paid for them. Sometimes this constraint is easy to work around as parts may be sold at a lower price by default. However, this is not always the case. A lot of time, the quality must be sacrificed in order to keep the price as low as possible.

This decision has been made multiple times in this project. For example, when choosing the microcontroller board, the cost paid a major role in the final decision. In the end, it was decided that the Arduino Nano Every was the best fit. Even though there were other boards with better parameters that would allow for more wiggle room in the design process and a higher quality end product, they cost about double the price of the selected board if not more. This would increase production cost, increase consumer cost, and decrease the likability of the product. Therefore, the cheaper Arduino Nano Every way chosen. Although its parameters were not as good as some of its competitors, it provided enough for the necessary functions of the project and therefore, was chosen in the final decision.

The second social constraint to be considered is how easy it is to install. One quality of the human race is that just about everyone is lazy. It is more favorable for the public to do as little work as possible in order to get a new item working. They would rather spend a little more money on something that takes 5 minutes to install rather than its cheaper counterpart that takes an hour. This is another constraint that should be taken into consideration. It is important that this project is designed so that it can be installed in as little time as possible. This means that it's best to assure that as many parts as possible are in place at time of purchase and that the instructions are made clear. That way, the consumer can easily implement the system for use.

This constraint can certainly be taken into consideration for this project. For example, there are several ways of designing the final product. It could be designed so that the sensors, shading system, and irrigation system as separate pieces. The user would have to take the pieces, place them in the pot, and connect them to the microcontroller so that it all can function. Although this design will allow for use of any pot and a lower price, it will require the user to do work. This can be rather challenging to implement if the user is not tech-savvy as there is a lot of room for error. Another implementation involves the sensors and two systems already being built into a pre-designed pot. The sensors and two systems will have already been placed into the pot and connected to the power system and microcontroller at the time of manufacturing. This implementation is much more ideal than the last. Although this product cannot be used on any type of board and the cost will rise, the ease of installation is much higher. This design better conquers the social constraint and assures the public will think highly of it.

A third social constraint is the ease of use. All products must be easy to use in order to be liked by the general public. For example, a product with a lot of tabs or buttons with large functions can be overwhelming at first. This can lead to a less desirable review of the product and lower sales. Condensing those tabs of buttons into smaller sections that are easy to navigate is more ideal. The second product will have better conquered the social constraint as the general public will like it better and be more inclined to purchase it.

Ease of use can mean many things depending on the product. For example, an easy-to-use product for a toddler would look very different from that of a scientist. If a device was being developed for a child, it would probably include big buttons with bright colors. Knowing their short attention span, there would be little to no instructions associated with the product resulting in little functionality. On the other hand, if the same product were designed for an intellectual adult, it would look very different. It may not be as bright and colorful but can easily implement higher functionality through an instruction pamphlet or a video that explains how to use the product. The adult is better able to understand more complicated products and therefore, would be okay with something that takes a little work to understand. Overall, the definition of easy to use depends entirely on the target audience itself.

This project will take several steps to overcome this constraint. The application is a prime example of this constraint. There are several functions that should be incorporated into this app like inserting data about the plant as well as buttons to manually start and stop the irrigation and shading systems. There are many ways of implementing these functions. One is to condense them to one page. Although this method would allow for a smaller file size, it will be harder for the user to use. Having all functions on one page will make it overwhelming to look at and hard to navigate. Another design involves separating the functions to multiple pages and having a homepage that will allow for navigation between them. Although this design is larger, the design will be much smoother and less condensed. The app will be less overwhelming and the functions easier to find. This design is more ideal. It helps overcome the social constraint by providing an easy-to-use experience for the user.

The last social constraint is the size of the final product. Choosing the correct size is always important in the design process. Depending on the components used and the use of the product, this can vary greatly. Generally, it is more desirable to produce a product that is smaller in size. A smaller product is easier to carry and move around when desired. As the product increases in size, it can become too bulky or heavy and eventually too large for a consumer to use. The size of the final product must be taken into consideration when designing.

This constraint is a bit challenging for this particular project. Plants come in a wide variety of sizes. Some are small like a daisy or grass. Others are very large like a cactus or a pine tree. In order to create a product usable with plants of all sizes, the pot would have to be incredibly large. This is unrealistic and will cause problems with its likability. In order to balance this constraint while incorporating as many plants as possible, a size limit must be chosen. Choosing a smaller size would be great as a smaller size will increase the public's view of it. However, this will result in many plants outgrowing their pot and ultimately destroying their sales. Choosing a larger size will allow for incorporation of a large number of plants but may result in a product that is too large for the general public and will cause sales to plummet. For this reason, this constraint proves to be a challenging factor that must be overcome in the final product. The choice of pot size must be small enough to be considered desirable but also large enough to be used for a wide variety of plants.

Another reason this constraint can be challenging is the importance of weight in this project. Pots are generally pretty lightweight. This allows them to be moved around easily and at the discretion of the user. As the pot becomes larger in weight, it becomes harder to carry which will be harder to move. This is less desirable, so the pot should be kept as light as possible. The issue is that all components of the system will have weight. All sensors and all systems will cause the final product to weigh more than the average pot. The addition of extra sensors or an increase in the amount of water stored will ultimately increase the weight of the final product. This will cause a drop in sales as a heavy pot is not desirable. Therefore, it is ideal to keep the final product as lightweight as possible so that it is more favorable in the eye of the public.

4.1.4 Ethical Constraints

When it comes to the ethical constraints of our system, there are several areas that must be taken note of in order to give proper credit for our work. The first major area that is important with the ethical system of this project is the area concerning properly citing sources. When each student finds a source, they must properly cite it as to not plagiarize the information. Also, because images are subject to copyright, permission must be asked of the owner before any image is inserted within the project. The second area that is important concerning the ethics of this project, is the area concerning related works. It is important that each student stay clear of other projects that are too similar, as to ensure the originality of their own ideas. It would be very unethical to just look at what others have done in the past on a similar project and copy their implementation down directly. Finally, one must make sure to properly advertise the project according to its functionality and features as to not mislead any potential buyer. Although it may be tempting to make the product sound better than it is, it is important to be honest about the power consumption, durability, and functionality of the product as a whole. Overall, there are several areas concerning the ethical completion of this project that we must take care to complete with integrity.

4.1.5 Health and Safety Constraints

Health and safety constraints play a major role in everything that we do today and all of the products that we produce. From a simple pencil to the cars that we drive, all products were created with health and safety constraints in mind. Health and safety constraints deal with the protection of the health and safety of the general public. They assist by assuring that the product will have little to no effect on people's safety when in use. These constraints can be found throughout the entire lifecycle of a product. Some are placed during the designing and prototyping stages while others make their debut once the product has been purchased by a consumer. These constraints will always be present and must be considered by the engineers who are designing.

Health and safety constraints cover a wide variety of topics. They stretch from the toxic levels within a material to the brightness and volume of a television. They limit the design to assure that everyone involved remains as safe as possible. All aspects of the product as well as its installation and operation have health and safety constraints associated with them.

Moreover, these constraints can be seen in all lines of business. For example, the material chosen for the window of a plane is not a coincidence. Although a cheaper material would have allowed for a cheaper overall price, it would not have ensured the safety of the passengers on board. Therefore, a more expensive material that is strong enough to assure that nothing would break while travelling at higher speed was chosen. Another prime example is the design of the butter knife. The purpose of this knife is to easily cut through food so that it can be eaten. When choosing the sharpness of the blade, it is more ideal to have a knife that is sharper. That way, it would be able to cut through any food that it comes across. However, this is not always ideal. If the sharp knife got into the hands of someone less responsible, it could potentially cut them or lead to much more serious and dangerous consequences. Therefore, the designers of the simple butter knife scaled down the level of sharpness to assure that no one would get hurt but was still able to cut through the food as intended.

Failure to work these constraints into the design on the product can lead to rather serious consequences. A small papercut caused by a thin piece of paper within the product is nothing and probably will not lead to anything bad. However, if a phone short-circuits, catches on fire, and kills the user and several people around, then there will be an issue. The company that designed the product will be held fully responsible for anything that may happen to a consumer while their product is in use. These can lead to lawsuits or in the most drastic case, shutting down of the company and potential jail time for those responsible. All of these are of course undesirable and can easily be avoided by taking the health and safety constraints into consideration while designing the new product.

Many of these constraints, while dangerous and important to acknowledge, are unavoidable and cannot be taken out entirely. For example, although it would be safer to drive a car at a slower speed, most people prefer to drive them fast. This allows them to reach their destination in the shortest time possible. Although putting restrictions of the capabilities of the car so that it will drive slower would make it safer, the general public would not like that and would be less inclined to buy it. Therefore, other mechanisms – like the seatbelt and airbags – have been put into place to make up for the safety issue that arises. This is a prime example of how health and safety constraints can be addressed without flat out removing the problematic component.

This project, like all others, has a large number of health and safety constraints that should be addressed while designing. To start, we have some obvious issues that are typical for electronic devices. The first issue involves the use of the battery. A battery, an essential component of this device and its ability to function properly, has a great deal of safety constraints when in use. First of all, the battery must provide the correct amount of voltage for the circuit. Otherwise, there is the potential of too much power getting in, causing a component to overheat and the inevitable electrical fire. (Wilson) If the battery is placed with the terminals in the wrong direction and no protection circuit is in place, there is the chance of the system becoming unstable and again causing an electrical fire. If a flammable material is placed near the terminals and enough electricity is conducted through it, this also has the potential of causing an electrical fire. (*Connected Jumper Cables*) The list goes on with batteries and so the safe usage of them plays a major role in the design of the final product.

Another safety constraint is the possibility of shocking someone. All parts of the project that conduct electricity must be fully insulated in order to assure that no one gets hurt. If not, if the consumer touches a part of one of those exposed parts, they will become a new conductor of the flowing electricity and get shocked. Depending on the amount of electricity that enters their body, this can result in a small static shock to potentially kill them. (*The effects of an electric shock*) Now this project will not work with large voltages, so there is very little chance of the second option coming true. However, it is possible for someone to get a serious shock that will cost them a hospital visit. Therefore, it is important that the project is designed so that there are no exposed wires to limit the chances of someone getting hurt.

Another issue that arises regarding exposed wires is the weather. The project is meant to autonomously take care of a plant and can be placed inside or outside. If the product was placed outside, there is a chance that it will get rained on. If that happens, water, which is a very conductive material, may get into the circuitry. If it does and there is an exposed wire, the water could cause a spark and a potential for the product to catch on fire. (Bayside Staff) For this reason, it is important that the circuitry be protected from external forces. That way, there is no chance of rainwater getting in and destroying the hardware.

This leads to another health and safety constraint which involves the light sensor. The purpose of the light sensor is to detect the amount of sunlight being received by the plant. In order to detect the sunlight, it will be placed directly in the path of the Sun so that it can receive the maximum amount of light. The sensor will have a range of lux values that it can correctly identify. If the sunlight were to produce a lux level above that threshold, there can be potential problems. For instance, if the lux were to stay over that threshold for a long period of time, the sensor could overheat and catch on fire. (M. and Lathrop) If the product is utilized in a place closer to the equator while receives a tremendous amount of sunlight and high lux levels on a daily basis, there is a great chance that this accident will occur. (Davies) Therefore, the sensor must be chosen so that it can handle the direct sunlight for long periods of time without overheating. This limits the type of sensor that can be chosen. Potentially, a more expensive light sensor will be required to assure the safety of those using it.

Overheating components not only could start electrical fires, but also have the potential of burning someone. If, for example, the light sensor begins to overheat, the newly created heat will try to escape the device to a colder object, whether this be the air surrounding it or the pot itself. If a human were to touch the sensor while it was overheating, the heat will try to move to the person’s skin causing it to burn. Depending on the temperature of the sensor and the amount of heat it has, the person could get a serious burn that will require a trip to the hospital. (*Burns*) This could happen to any of the components on board including the microcontroller, the battery, and even the shading system. Therefore, it is important for the designers to keep the possibility of overheating in mind when designing so that this type of accident can be avoided.

There are also safety constraints involved with the other systems of the project. For example, the irrigation system and its water pressure. The irrigation system has the responsibility of watering the plant when given the signal. It does so by using water pressure to pour water into the soil around the plant. This system would be more ideal at a higher water pressure. This will allow the system to spray water farther and in turn, cover more areas of the plant with water. However, higher water pressure can lead to a higher chance of injury. If the water pressure was too high, it could seriously hurt someone. The hoses used to pressure wash the floor or windows are at such a high pressure that they could seriously hurt someone and send them to the hospital. This project will not be using anything of that sort, but still could potentially cause a bruise or break a small finger. (Peterson) The designer responsible for this system must be aware of this issue and design pipes that use a lower pressure for the safety of the public that is also high enough to cover the necessary amount of the plant.

The use of water in this system can also cause another constraint to arise. As stated above, water is very conductive and can cause serious problems with the project. Like with the rain, the water being used to water the plant has the potential of leaking into the circuitry of the project. This could lead to destruction of the hardware from a short-circuit and even an electrical fire. (Bayside Staff) This constraint will require that the water used for the plant be placed as far away from the circuitry as possible in order to limit any possible contact of the two. This also means that the pipes should be made of a solid material that will not leak and a form of absorbent material should be placed between the two. This idea must be kept in mind when designing the layout and placing the final components within the project.

The water used for the plant can pose several risks to the health and safety of the population. Certain water used daily in our world is labeled as non-potable. This means that it has not been filtered and potentially contains chemicals that are harmful to humans. Plants do not have this same restriction. They can use non-potable water and survive. Therefore, the plants within the project would be able to work with the cheaper non-potable water. However, the use of this water will create a safety concern. While it is not recommended to drink the water used for the plants, it is possible that someone who is not able to comprehend the severity of such an act will drink the water. This can create health issues for that person and will most likely lead them to a hospital. (*Health Problems*) This is a health and safety constraints for the project. Although it may be cheaper to utilize non-potable water for the project, it may not be in the best interest of the public. Using water that has been filtered will limit the risk of someone getting sick from drinking the water.

Water also has the potential of causing corrosion. Corrosion is inevitable and will occur regardless of the type of material chosen. Water has the natural ability to accelerate the process meaning that the pipes within the irrigation system will potentially get rusty at a faster rate than intended. If the pipes get too rusty, they will break, causing water to spill everywhere. (McFarland et al.) This can be a slipping hazard, not to mention the rusty pieces of metal lying on the floor. If an animal or small child were to ingest it, they could have digestion issues. (Gotter) If a person were to step on it, it could get lodged in their foot and potentially cause an infection. (Higuera) If the water were to spill into the circuitry, it could cause a short-circuit and potentially cause an electrical fire. (Bayside Staff) This constraint will require that the pipes be designed carefully with a material that is less prone to corrosion as well as a system to assure that there is very little chance of the pipes breaking.

The weight of the pot is another health and safety constraint. The general population is only so strong and has a limited amount of weight that they can carry at one time. While that number varies from person to person, there is a limit to how much the average person can carry. Given that this project will be designed for the average person to pick up, there is a weight limit on it too. If the project were to get too heavy, it could hurt someone. They could throughout their back while carrying it or even drop it on their foot and break a bone. (Hamilton) The final product must be designed to weigh as little as possible to limit the chances of someone getting hurt while picking it up.

The shading system itself has many potential safety risks that will cause health and safety constraints to arise. The shading system will be similar to a foldable fan, meaning that it will fold out when given the signal to provide shade for the plant. It will consist of metal blades that hold an umbrella-like material for protecting the plant from the Sun's rays. This system can be potentially dangerous and has several health and safety constraints to ensure the safety of those using it. For one, the metal blades possess a safety risk. They must not be sharp enough to potentially hurt someone if they come in contact. If the blades are sharp enough, they could cut someone who brushes up against it. While unfolding, they could seriously injure someone who is simply passing by. This could lead to serious cuts that require stitches. (*Cuts*) This is the reason for the safety constraint. The blades of the shading system should be designed in such a fashion that they do not have the ability to cut someone nearby.

Another risk involved with the shading system is the speed. The blades of the shading system will be required to rotate around an axis when unfolding and folding back up. Depending on the motor controlling it, they will open and close at a certain speed which can be determined by the designer. If the designer chooses to make the metal rods open at a faster speed, they could potentially hurt someone. For example, if someone is reaching into the pole's path when the system decides to open, if it is moving too fast, the person could get hurt. The speed and weight of the blades could lead to a bruise of a potential broken bone for a fragile person. (Jaliman) Therefore, there is a constraint on the speed. The designer must choose a speed that is lower to ensure that no one will get hurt when the shading system decides to deploy.

Another issue arises from the rotational system. This system is responsible for rotating the plant in a circle to ensure that all sides of the plant receive the same amount of sunlight and that the plant will grow upward rather than at an angle. Like anything that moves, there is a risk of someone getting hurt by it. For example, an issue could potentially arise when someone is nearby, and the system is active. The design of the system will result in an edge and a small gap between the portion that rotates and the portion that does not. If someone or something were to get stuck, they could potentially get hurt. A small finger caught between the two could become sprained (*Finger Sprains*). A piece of clothing could get torn in half. This constraint will limit the design and implementation of the rotational system. The designer must be aware of this possibility and limit the gap created by the two halves and try to create a safety mechanism to prevent anything from getting caught.

The rotational system also poses a risk with its speed. Like the shading system, the rotational system will be rotating on an axis. The faster the rotation, the more ideal the outcome. However, if the system were to rotate too fast, it could cause an accident. For one, if someone is in close proximity to the pot or plant, they could get hit by one of the components on board. The faster the speed, the more likely they are to get seriously hurt and require a hospital visit. Another risk is the possibility of something flying out of the pot. All plants are required to be planted in dirt which will be sitting freely within the pot. If the rotational system spins too fast, some of the dirt will fly out. If someone is within the range of the projectile, they may get hit by it. If hit in the right place, it could seriously injure them. (Jaliman) For these reasons, there should be a limit to how fast the rotational system can go. The designer should create a system that is fast enough to satisfy the needs of the projective without causing risk of injury.

This particular section only scratches the surface of the health and safety constraints associated with this project. There are plenty more issues that could pose a risk to the health and safety of those who use it. With all of these constraints, the thought may cross someone's mind to not bother completing the project. Health and safety constraints are inevitable with any new design. There is always the chance that someone could get hurt while using a new project. Therefore, these constraints should not discourage one from designing something new. In fact, they should do the opposite. Instead of viewing all that could go wrong, it is better to view this as an opportunity. If the project is successfully implemented while following all of the health and safety constraints, this means that the designer has successfully created a product that will make the world a better place.

4.1.6 Manufacturability Constraints

Manufacturability constraints consist in designing a product in a way it can be manufactured. In this case, the main product will be constructed by the member of the group by performing research on standards and common practices performed in similar products on the market. This fact limits the manufacturability of the final product to the services, materials, and equipment available to us. This limitation could affect the efficiency, performance, and operation of the final design since some mechanisms need high technologies to be designed. However, the research of best available services, materials and equipment has been done and will continue to be done through the completion of the project design to assure a quality final product.

The materials used for manufacturing this project design should be easy to access through local industries or international industries with a reasonable shipment period. Most of the products to be used in this project design come from different places in the United States and even from other countries. This is a realistic constraint that must be considered in the selection of each part since there is a deadline that must be met.

In addition, the design must be easy to manufacture given the present manufacturing capabilities of the members and the environmental and social realistic constraints faced during this period. Due to the pandemic, each member of the group is working in his or her own part to be included once everything is completed to minimize the contact and interaction of the members. This limits us from the interaction required to manufacture the final product. To this it can be included the fact that not all members have access to testing equipment at the time a part is gathered, or a circuit is built. This limits the manufacturability of the product since each part must be tested before all of them are assembled in the final design, and we have to schedule specific times to meet up since everyone has different class and working schedules.

Another manufacturing constraint is to design a device or product that has the lowest number of assembly parts to provide the customer with an easy to install product. This is one of the targets of the marketing and engineering requirements specified in this project. So, all the components need to be manufactured in a way that they are easy to assemble in a small amount of time. However, the project design consists of different mechanisms and sensors to provide the plant with a healthy environment to grow. This makes us to design a product where different components are integrated in one single piece to minimize the assembly time. Nevertheless, there are systems such as the irrigation system that require a well design and manufacture to avoid the irrigation lines to be twisted by the rotation system included.

Since this project design is intended to grow an outdoor plant without much human interaction, it will be exposed to different climates. Therefore, the materials selected in the project design must consider the possible scenarios where the equipment could potentially end up. Factors such as sunlight intensity, salt and ammonia concentrations, winds, high and low temperatures, among others must be considered in the design. This requires from us different research in these topics with respect to all the components selected to manufacture a product that can serve different customers.

On the other hand, one of the engineering and marketing requirement specifications is the cost of the final product. Even though it is wanted to be maintained low, also the best affordable and available technologies are wanted in this project design. This is a realistic manufacturability constraint since the components or devices to be manufactured must consider the cost but also the quality of each element to be integrated. This increases the tests to be performed in each manufactured component to assure a final design that provided good performance, efficiency, and operation.

To the engineering and marketing requirement specifications, the size of the project design is included. This creates a manufacturability constraint since the components need to be manufactured in a manner that all the components fit within specified dimensions. This has an effect on the size of each component designed or selected as well as an effect on the manufacturability since the equipment available and experience with different equipment is limited.

If each component to be integrated in the project design is considered, different manufacturability constraints can be addressed. All the members of the group belong to the Electrical Engineering Department of the University of Central Florida. However, the project design contains different electromechanical components for which we have knowledge on their electrical side and not on their mechanical construction or behavior. This limited us to buy existing products rather than designing them from scratch to ensure their performance while they are operated. This is the case for the shading, irrigation, and rotation subsystems. For these subsystems, different motors and pumps must be included which are to be bought directly from a vendor due to our limitations in knowledge and available equipment to manufacture them. In addition, the sensors, microcontroller ship, solar panel, and battery will be bought directly from a vendor since we do not have the complete knowledge of their manufacturing process. These components must not be required to purchase in bulk since only few copies are needed for testing and integration. So, each vendor's specification about the required amount to purchase must be considered to avoid manufacturability constraints. However, the voltage regulator, circuit board, and solar charge controller will be designed and manufactured in a laboratory environment to test their functionality so that they can be integrated on a printed circuit board or PCB in the final design.

The printed circuit board or PCB manufacturing represents a potential manufacturability constraint due to the current pandemic. A lot of vendors and manufacturers are having delays on the production and shipment of their products. This potentially affects the time and manufacturing of the final product since we depend on their availability, manufacturing, and shipment of their products to assemble and test the final project design. Therefore, the overall design and schematics must be completed as soon as possible to send them for manufacturing and test their operation. If a circuit board does not work properly or does not provide the desired output, it must be redesigned and remanufactured for future tests and improvements. It is important to recognize that most of the manufacturers of printed circuit boards or PCB are from other countries where the pandemic is currently present. This could possibly affect even more the manufacturability of the final product since there are some limitations and restrictions on the shipment of different products from certain countries. Therefore, different vendors must be considered when selecting different parts for the project design, since we cannot rely on just one supplier due to the production and availability factors.

4.1.7 Sustainability Constraints

Sustainability constraints relate to the ability of a product in maintaining certain operational levels when exposed to different environmental, electromechanical, human, among other factors. The project design is intended to be durable and sustainable besides the conditions it can face in an outdoor environment. Being an outdoor product exposes it to different climates factors such as rain, wind, low and high temperatures, sun radiation, among others. Also, it exposes the product to different animals such as bugs and wildlife. The interaction of these factors with the overall product can cause different behaviors on the product operation such as overheating, instability, and short lifespan if it is not properly designed.

It is important to select materials and components that can resist different climates to avoid corrosion and malfunction of the system. The shading system must be constructed from a durable, anti-corrosion material to ensure it is going to operate properly even if it is raining. The same happens with the rotation system. Their motors must be covered with a resistant material to avoid malfunctions. On the other hand, the irrigation system water pump will be covered in the enclosure which protects it from different climate factors.

In addition, the electrical components must be covered properly to avoid short circuits, overrated or underrated voltage and current levels, or any other electrical failures. Among the electrical components are the PCB, sensors, battery, solar panel, and wires. These components must be protected to provide safe operation levels for each one of them. The protection of these components is a must since they carry electricity which can present potential hazards to the product, environment, and human being if not properly protected. This is something that must be avoided by the selection of proper components and enclosures to assure the safety of human beings, environment, and the product itself.

The sun radiation and temperature are important factors to be considered in the sustainability of the project design. The direct exposure to sunlight and elevated temperatures, can cause the system to overheat which consequently causes the system to malfunction. This factor made us to select components and materials that can operate and maintain their physical and behavioral aspects when exposed to high or low temperatures. All the motors and electrical components must be selected based on their operational temperature ranges since the project design is to be an outdoor product. Even though weather forecasts are predicted, sometimes unpredictable phenomena occur since we do not have control over it. So, the components must be able to operate over a wide range of temperature to compensate for unpredictable occurrences.

All the previous factors mentioned could possibly affect the stability of the system. If the system is overheated, the voltages and currents can become unstable affecting the overall stability. This can cause the sensors to obtain wrong measurements providing erroneous data to the controller and the applications. This in fact can cause the electromechanical systems to operate at wrong times causing the overall system to crash and become unstable. The stability of the system is very important since this affects all the components and represents a hazard for the environment, human beings, and the product itself. So, the component must be selected in a way that the stability of the system is optimized to assure the sustainability of the overall product even when facing severe conditions.

Since the purpose of this project design is to reduce the human interaction while growing a plant, the system must be made of long-lasting materials to avoid the need for changing any of the components or the overall product. All the enclosures, and exposed material must be of good quality to ensure the system is sustainable.

4.2 Related Standards

This section introduces some related standards for the project design. Battery standards and programming language standards are discussed in this section.

4.2.1 Battery Standards

This project requires the use of a battery to store the charge generated from the photovoltaic cell or solar panel. Some standards apply to this battery to assure a safe operation. These standards are discussed in this section.

UN/DOT 38.3

The United Nations (UN) provides recommendations on the transport of dangerous goods defined in the Manual of Tests and Criteria, Part III, Section 38.3. Since lithium batteries are classified as Class 9 dangerous goods during transport, they must meet the provisions established in UN/DOT 38.3. This standard relates to the transportation, either by sea, air, rail, or roadways, of lithium-ion batteries. Since they are classified to be dangerous, their transportation must follow certain safety protocols. The general protocol established in this standard includes identifying/classifying lithium batteries; testing/qualification requirements; design guidance/conditions and packaging/shipping obligations.

IEC 62133

This standard specifies requirements and tests to operate in a safely manner portable sealed secondary lithium cells and batteries that do not contain acid electrolyte, under intended use and reasonably foreseeable misuse. It specifies the exporting of lithium-ion batteries used in IT equipment, tools, laboratory, household, and medical equipment.

UL 2054

This standard specifies requirements about portable primary (non-rechargeable) and secondary (rechargeable) lithium-ion batteries for use as a power supply in goods. Also, this standard intends to reduce the risk of explosion or fire when fire when lithium-ion batteries are working in a device, to cover lithium-ion batteries for general use, to reduce the risk of injury when removing lithium ion batteries from a product to be transported, stocked, or discarded after it has caught fire or exploded.

UL 1642

This standard is used for testing lithium cells. The requirements included in this standard cover primary (non-rechargeable) and secondary (rechargeable) lithium batteries for use as power source in products; lithium batteries intended for use in technical-replaceable or user-replaceable applications; reducing the risk of fire or explosion in products using lithium batteries; reducing the risk of injury after fire or explosion of lithium batteries when the user removes the battery from the product. In addition, this standard covers technician-replaceable lithium batteries that contain 5.0g (0.18 ounces) or less of metallic lithium, and user-replaceable lithium batteries that contain 4.0g (0.13 ounces) or less of metallic lithium with not more than 1.0g (0.04 ounces) of metallic lithium in each electromechanical cell. This standard relates to the previous standard discussed, UL 2054. However, UL 2054 covers battery level tests, which is not covered in UL 1642.

UL 1973

This standard covers the requirements for safety batteries for use in stationary, vehicle auxiliary power and light electric rail (LER) applications. The standard covers battery systems used as energy storage for stationary applications such as for PV, wind turbine storage or for UPS, among other applications.

ANSI C18.2M

This standard provides specification for standardized portable lithium-ion, nickel cadmium, and nickel metal hydride rechargeable cells and batteries to ensure their safe operation under normal use and reasonably foreseeable misuse. Also, this standard covers relevant information to hazard avoidance.

4.2.2 Solar Panel Standards

This project design will be powered via a solar panel that will recharge a lithium ion battery to power the entire system including the sensors, microcontroller, and electromechanical subsystems. To design a safe design, some related standards are discussed.

IEC 61215

This standard is for crystalline silicon terrestrial PV modules. It is one of the most important standards for residential solar panels. It applies to both monocrystalline and polycrystalline PV modules. The solar panels tested under this standard are tested on electrical characteristics (wet leakage current, insulation resistance), mechanical load test (wind and snow), and climate tests (hot spots, UV exposure, humidity-freeze, damp heat, hail impact, outdoor exposure. Also, this standard helps in determining a panel's performance metrics at standard test conditions (STC) which include temperature coefficient, open-circuit voltage, and maximum output power.

IEC 61730

This standard specifies solar panel's aspects related to their safety. This standard covers an assessment of the module's construction and the testing requirements to evaluate electrical, mechanical, thermal, and fire safety. More likely, this standard oversees the risk of electrical shock that solar panels carry if they are improperly built. Those solar panels that meet IEC 61730 standard have a low risk for these types of hazards.

IEC 62716

This standard covers the ammonia corrosion of photovoltaic (PV) modules for cases where solar panels are placed near a farm. This standard tests the module's resistance to ammonia which is present near farms and livestock. This type of corrosion accelerates the degradation of the solar panel which can cause a lower overall electricity production of the solar panel over the years. Even though this type of corrosion is not present in all places, it is a characteristic of the solar panel that must be considered to assure that any consumer can acquire this product.

IEC 61701

This standard covers the salt mist corrosion. This standard tests solar panels by spraying salt in a controlled environment to observe if they suffer any damage either physical or related to its electrical output and overall performance. This standard is important in designs containing solar panels since it assures that these systems can be placed in locations near beaches or where salt concentrations are elevated.

IEC 60068-2-68

This standard covers the solar panel resistance to blowing sand. It determined how well they work and maintain good operations in sandy desert environments. The exposure of solar panels to abrasive sand can cause physical and mechanical defects over time. This condition does not apply to every consumer, however, this will assure that

UL 1703

This standard is for flat-plate PV modules and panels. It addresses the safety and performance of solar panel modules. It is similar to IEC 61215 or 61703 tests. This standard tests for climatic and aging aspects. Also, it tests for safety aspects related to mechanical loads, fire, and electrical hazards.

UL 61730

This standard covers photovoltaic module safety qualifications. It is a combination of UL 1703 and IEC 61730 standards to provide a complete international approval for solar panel module's safety and performance.

4.2.3 Programming Language Standard

This project requires the use of a microcontroller which must be programmed in order for it to perform all necessary functions. The program will be written using the C language. The sections below will explore the various standards associated with this language.

IEEE 1178-1990

This standard defines the requirements for the C language. It defines how the language should be written and the functions that are included. It also included data regarding the syntax and implementation in order to assure all devices are able to read and utilize it. It was created by the C/MSC - Microprocessor Standards Committee and was published on November 30, 1990. It was withdrawn on November 7, 2019.

ISO/IEC 9899

This standard updates the specifications for the C language. It reworked the syntax and other features so that it can fit the newly developed computers. It also defines functions that will potentially become obsolete in the future. It was created by the ISO/IEC JTC 1/SC 22 technical committee and was published in November of 2007.

ISO/IEC 9899:2011

The purpose of this standard is to further increase its portability with newer devices. It redefines many of the functions and syntax to better fit the needs of the new computers. It assures that all computers up to that point were able to successfully process the C language. The standard was written by the ISO/IEC JTC 1/SC 22 technical committee and was published in December of 2011. It has been withdrawn.

ISO/IEC 9899:2018

This standard again updates the C language to be fully compatible with the newer machines. It updates many parts of the language including the syntax and semantic rules.

It was written by the ISO/IEC JTC 1/SC 22 technical committee and was published in June of 2018.

4.2.4 WiFi Standards

The microcontroller communicates the plant's environment status to the application via the WiFi Module. This module would need to follow the IEEE standards for Wifi as so not to communicate with a user's WiFi router correctly and not interfere with nearby radio waves.

IEEE 820.11a Standards

IEEE 820.11a is the original WiFi standard created in 1999, alongside 802.11a. It can transmit at 5 GHz and an average bandwidth of 50 Mbps. Since it costs more than the other standards, it is more common in work environments. But it has a shorter range due to its higher frequency and tends to be blocked by thick walls (Mitchell).

IEEE 820.11b Standards

IEEE 820.11b is the initial WiFi standard created in 1999, alongside 802.11a. It can transmit at 2.4 GHz and an average bandwidth of 2-3 Mbps. It is low cost and thus prevalent within households; in addition, it has a long range due to its low frequency. However, it is susceptible to interference by devices transmitting at that same frequency (Mitchell).

IEEE 820.11g Standards

IEEE 820.11g is a WiFi standard introduced in 2002. It merges 802.11a's higher bandwidth and 802.11b's frequency of 2.4 GHz. While very low cost and used by all modern WiFi-capable devices, it is the slowest of all the 820.11 family.

IEEE 820.11n Standards

IEEE 820.11n is a WiFi standard introduced in 2009 as an upgrade to 820.11g's bandwidth capability. It provides up to 600 Mbps of bandwidth. However, it has a higher cost than 820.11g (Mitchell).

4.2.5 Sensor Standards

Sensors detect information about the environment such as the presence of light, water content, and temperature. Depending on the manufacturer, these sensors might be made out of hazardous materials, and RoHS is a common standard that notes whether a sensor is free from harmful chemicals or not.

RoHS Standard

RoHS stands for Restriction on Hazardous Substances and is also referred to by Directive 2002/95/EC. European Union designed it to ban dangerous materials such as lead, mercury, and cadmium in electronics. These metals could lead to pollution and harm to humans exposed to it. All electronics free of such materials would have an RoHS label ("RoHS Compliance FAQ").

5.0 Design

When it came to the design of this project, the primary tool that was used was Solidworks. The advantage of using this tool was the vast array of options given to us, as well as the relative simplicity of the program which allowed it to be relatively easily picked up. The initial rough prototype design of the project can be seen in Figure 25 below, as well as a broken-up version of the design in Figure 26.

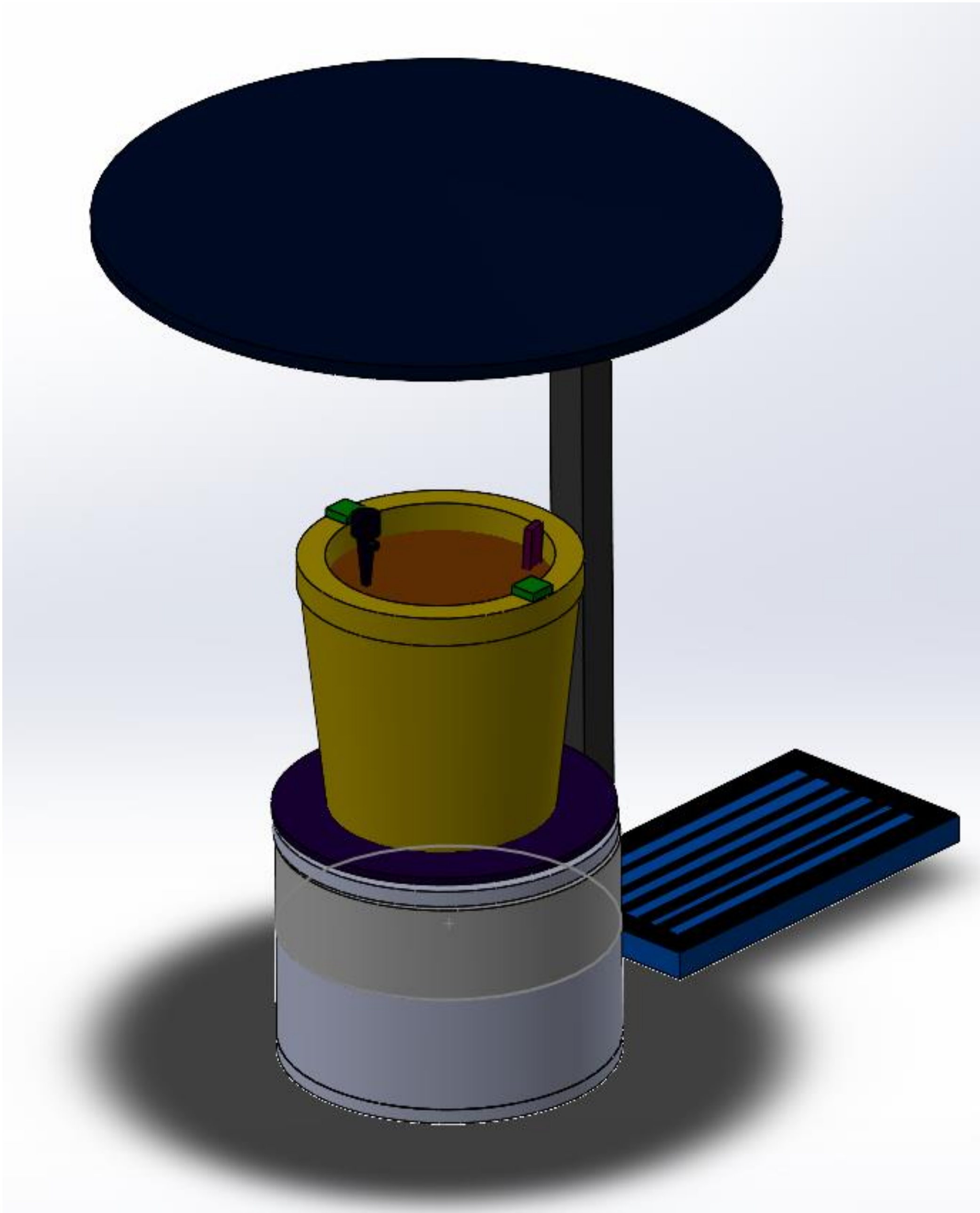


Figure 30: Assembled Solidworks Prototype of Project

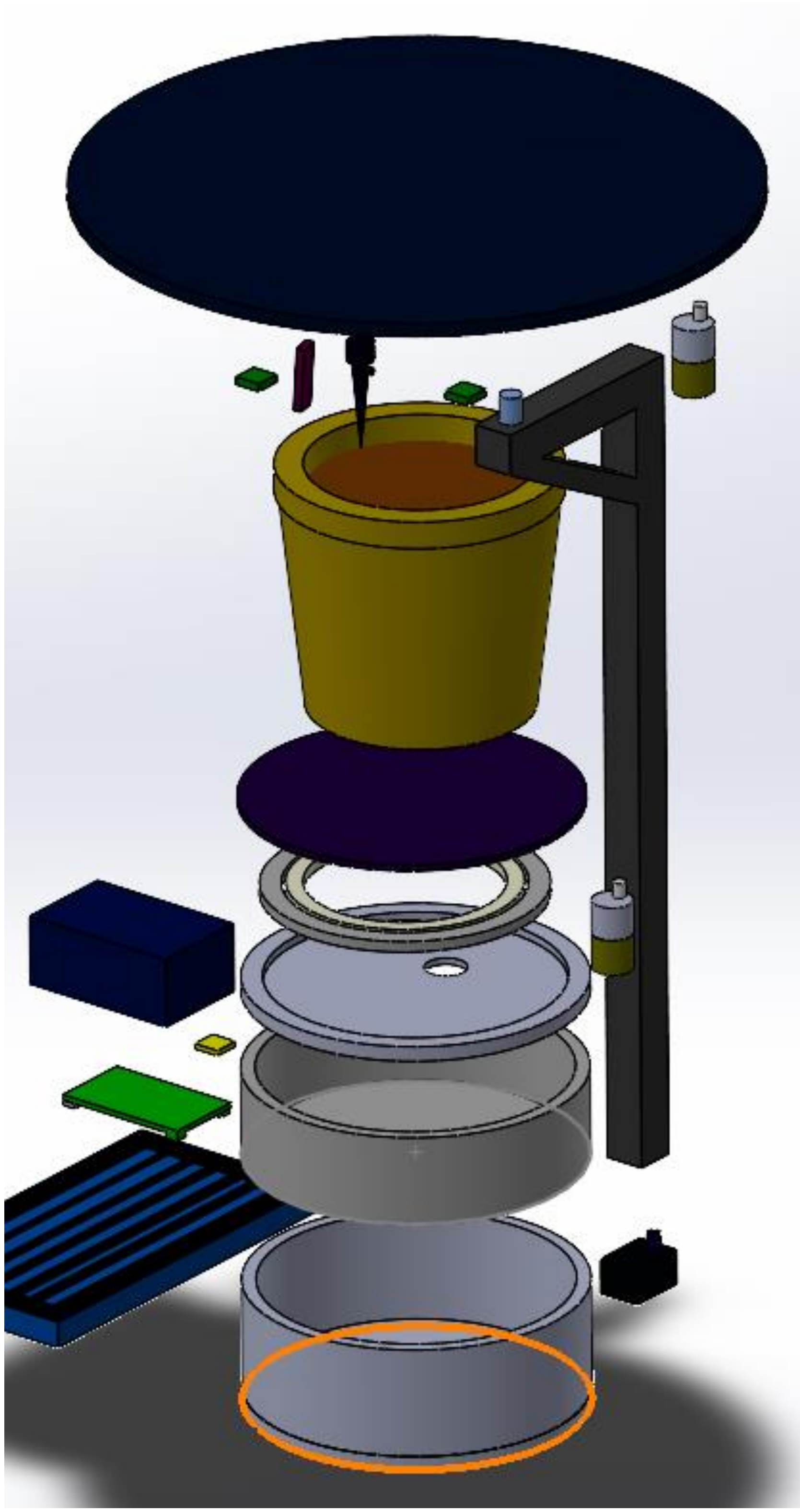


Figure 31: Dissembled Solidworks Prototype of Project

5.1 Water Basin

The first part that was assembled with Solidworks was the water containment section that sits at the base of the project. The outer diameter of this part is 12” and the height of it is 4.5”. The current inner diameter of this model is 11”, and the height is 4” so this results in a volume 380in^2 which is about 1.65 Gallons. This is an acceptable volume to carry enough water to supply the plant with moisture, while not being too large for the project as a whole. This portion of the project can be seen below in Figure 27.

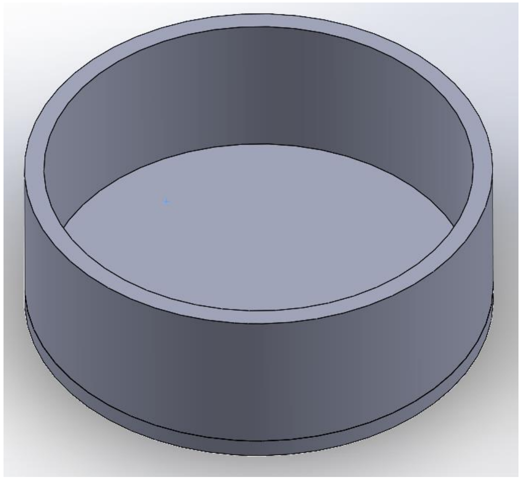


Figure 32: Lowermost Water Containment Unit

5.2 Water Pump

The second part that was added to the project with the Solidworks design program was the water pump. This pump will allow the water from the water basin to be pumped upwards to the pot containing the plant life. A picture of the water containment unit with the estimated sizing for the pump added can be seen below in Figure 28.

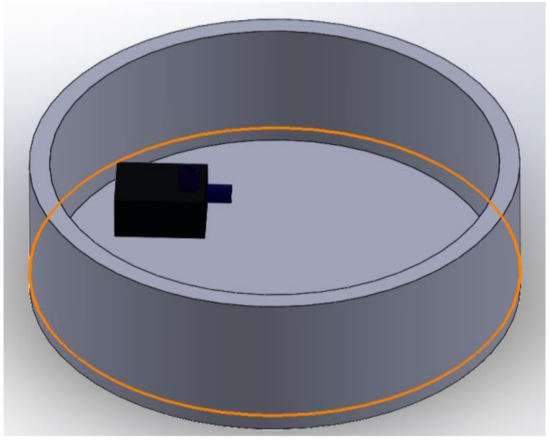


Figure 33: Water Pump Within Water Containment Unit

5.3 Electrical Storage Unit

The third piece that was added with the solid works program was the electronics storage section. This part is placed above the water containment unit in order to prevent any liquid from getting within the electrical components. The current size of the outside of this cylindrical piece is 3.25” tall with a diameter of 12”in. The inner diameter is 11” and the inner height is 3” giving us a internal volume of $285in^2$.This area is by far large enough to contain the battery, micro controller, PCB and light sensor. Below in Figure 29 one can see the storage unit emptily installed on top of the water basin, and in Figure 30 one can see the Light sensor (yellow), PCB(green) and battery(blue) placed within the unit.

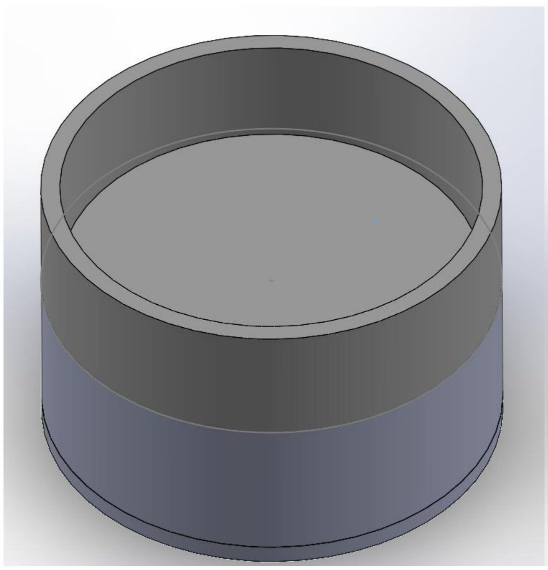


Figure 34: Electrical Storage Unit Empty

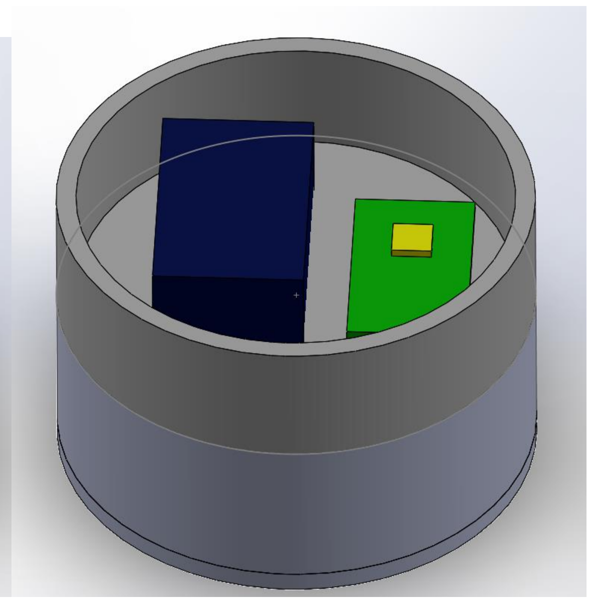
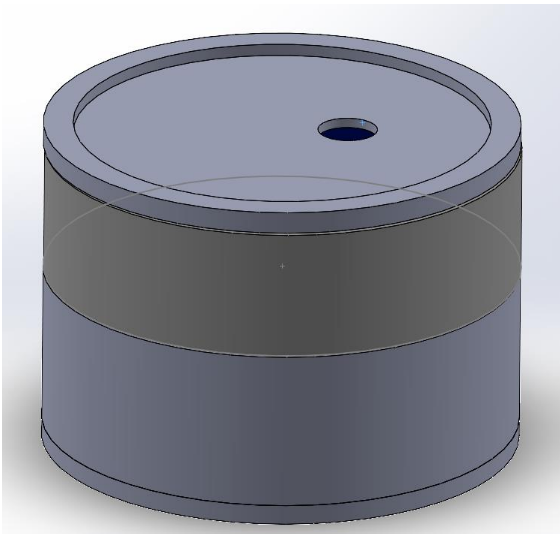


Figure 35: Electrical Storage Unit with Parts.

5.4 Electrical Containment Unit Top

The fourth component that was designed with Solidworks was the top piece to the previously mentioned Electrical Containment unit. This piece had to be designed with a protruding disk on the top, and a small hole towards one side in order to properly fit the rotational system and powering motor. The motor was then designed to exactly match that of the chosen motor for our project. In Figure 31 one can see the top piece installed on the unit, and in Figure 32 one can see the motor used to power the rotational system installed.



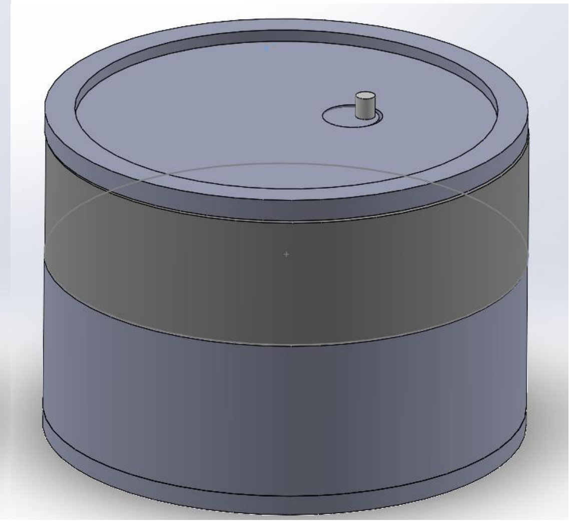
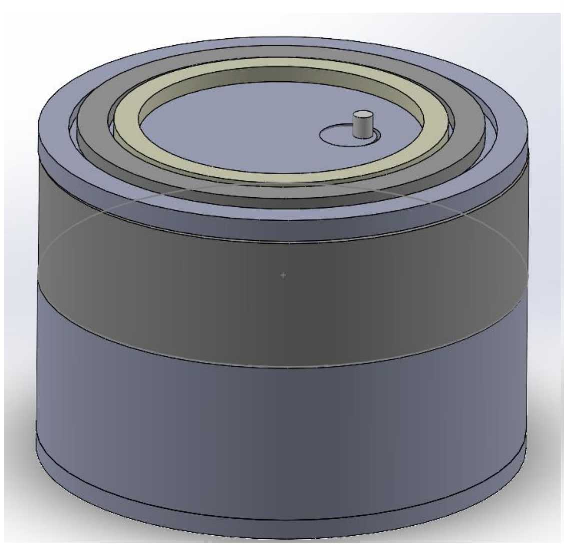


Figure 36: Electrical Storage Unit Top Installed Figure 37: Top with DC Motor Installed

5.5 Rotational System

The fifth piece that was added with Solidworks was the rotational system. The rotational system has an outer diameter of 10” and will be placed on the top of the previously mentioned electrical containment piece. The rotational system consists of two disks, the smaller of the two is slightly higher than the larger and is connected to the larger in a manner that allows rotation. The smaller disk is on the inside of the casing and will be connected to the motor so that it may be spun. In Figure 33 below, one can see the rotational system added, and in Figure 34, one can see the covering plate installed on top of the system.



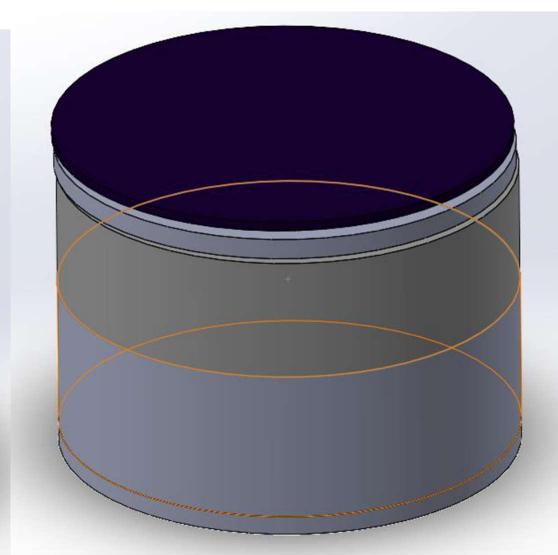
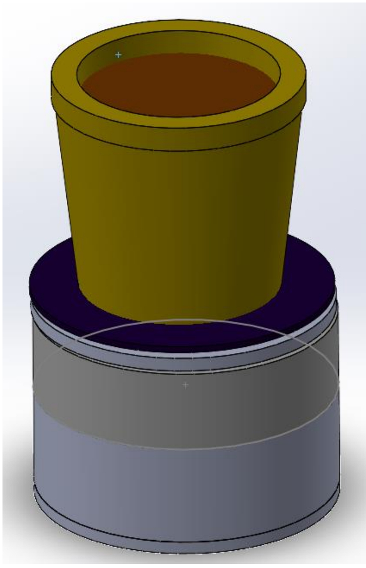


Figure 38: Rotational Disks Implemented Figure 39: Top Added to Rotational System

5.6 Pot and Water Emitter

The next set of pieces that was implemented into the project through the use of Solidworks was the pot for the plant itself, and the emitter that will connect to the water pump through the use of pipes. In Figure 35 one can see the addition of the pot to the project, and in Figure 36 one can see the addition of a water emitter. Note, that when the project is complete, there may be multiple emitters depending on the size of the plant and watering rate needed.



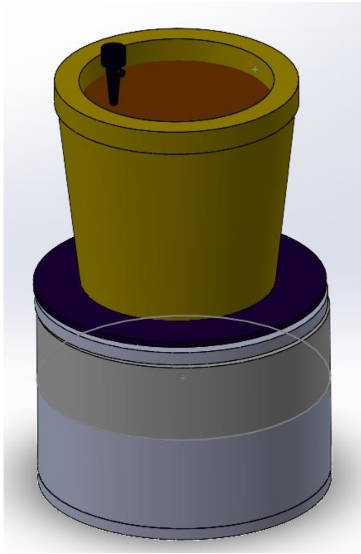


Figure 40: Pot Added Through Solidworks Figure 41: Emitter Inserted Within Dirt of Pot

5.7 Moisture Sensor and Light Sensors

The next set of pieces that was implemented to the project through Solidworks was the one moisture sensor, and the two light sensors. In Figure 37 one can see the addition of the moisture sensor, and in Figure 38 one can see the addition of the two light sensors. The reason there are two light sensors installed on the edges of the pot instead of one is so the intensity of the light on each side of the pot can be calculated in order to rotate the plant appropriately.

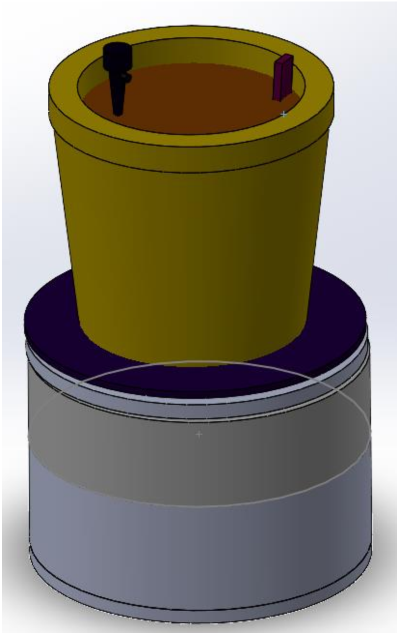


Figure 42: Moisture Sensor Installed on Pot

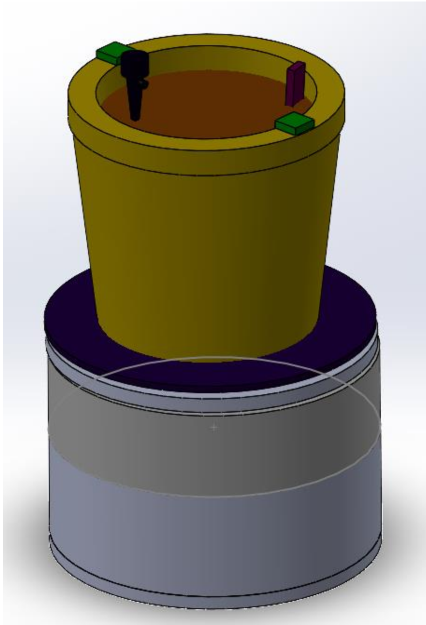


Figure 43: Light Sensors on Edges of Pot

5.8 Shading System Stand and Solar Cell

The next set of pieces that was added through the use of solid works was the shading system stand and the solar cell. The shading stand is used to support the shading covering and is implemented by attaching it to the side of the base. The shading stand is quite tall at a height of 30” in order to accommodate for the height of the base, pot, and plant. The addition of the shading stand and solar cell can be seen in the figures below.

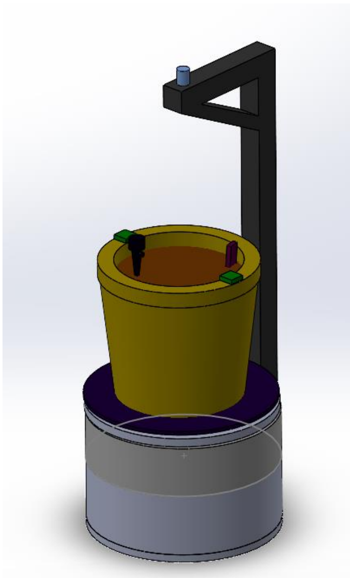


Figure 44: Shading Stand Implementation.

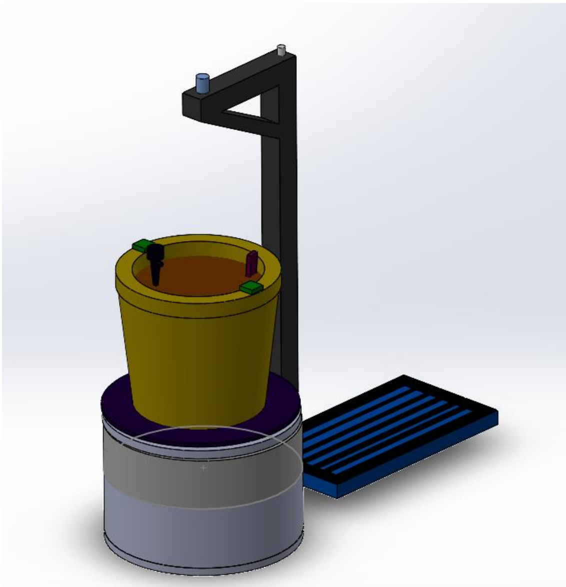


Figure 45: Solar Cell Addition.

5.9 Shading System

The final piece that was added through Solidworks was the shading covering. This is the one piece that was not properly modeled due to the students limited knowledge of the use of Solidworks. However, given the case that it is not completely accurate, the general shape still holds true. The way in which the implemented system will be different, is that the shading system will be foldable like a fan through the use of an electric motor that sits on the top of the shading system stand, and sheets of metal. The final implementation of the shading stand, and the system as a whole can be seen in Figure 42 shown below.

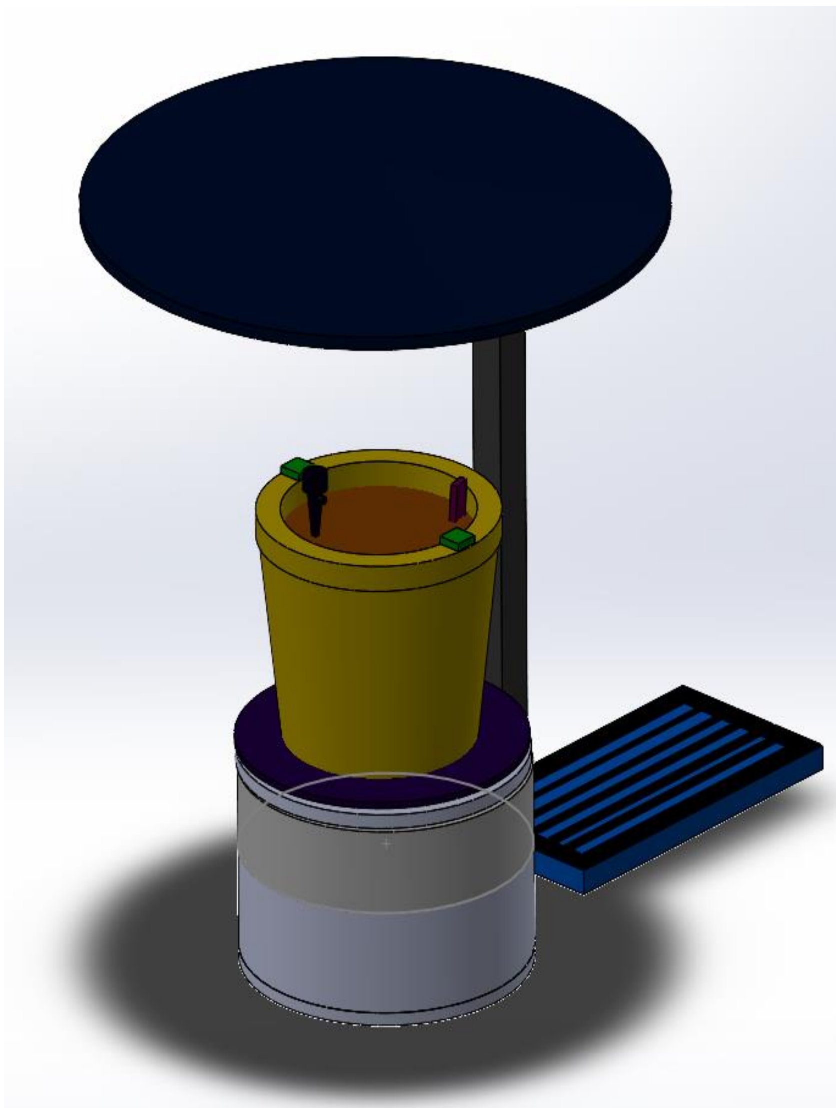


Figure 46: Project with Shading System Installed.

5.10 Voltage Regulators Design

Different components of the system require specific voltage levels to operate accordingly. Some of these components, like the sensors, require input voltages of 3.3V. On the other hand, the controller board has an operating voltage of 5V, which requires a voltage regulator to regulate the 12V supplied by the battery into the 5V required. To perform the required regulations, different designs were considered using linear voltage regulators, switching voltage regulators, and different DC/DC converter models generated on WEBENCH for specific condition levels.

5.10.1 Linear Voltage Regulators Designs

The linear voltage regulator to generate an output voltage of 3.3V will be designed using a similar approach as discussed previously for a general linear voltage regulator using resistors, capacitors, a transistor, and an operational amplifier. The selected LM7805 package cannot be used in this design since the output voltage to be generated is less than the required for this package. The design for a linear voltage regulator to generate a regulated output voltage of 3.3V will be as shown in the figure below. From this computer simulation it can be observed that the output voltage was regulated to approximately 3.3V. This measurement will vary by a few milliamps due to the resistors and capacitor tolerances.

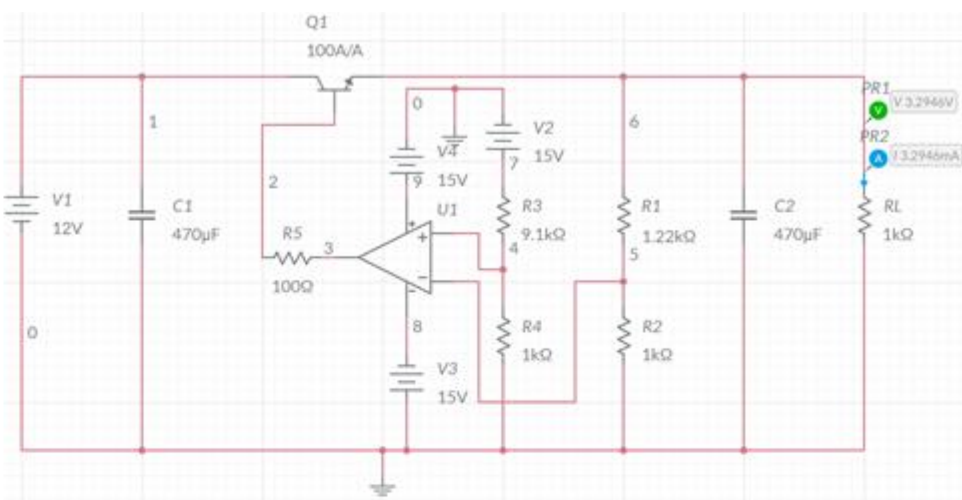


Figure 47: Designed 3.3V Linear Voltage Regulator

For the regulated output voltage of 5V required for the controller board used, the LM7805 fixed version will be designed following a similar approach as discussed in Section 3 of this document. The capacitors will be set to 470µF and the input voltage will be 12V. The load resistance can be varied on the testing environment to calculate the output current and voltage, and the efficiency of the design. In addition, it can be performed following a similar approach as done for the 3.3V voltage regulator shown in the previous figure. However, the resistances of R1 and R2 must be changed accordingly to produce an output voltage of 5V. To do so, R1 must be set to 2.367kΩ, which will be varied on the testing environment due to availability constraints, and R2 must be set to 1kΩ. From the next figure, it can be observed that the output voltage was regulated to approximately 5V. This measurement will vary by a few milliamps due to the resistors and capacitor tolerances.

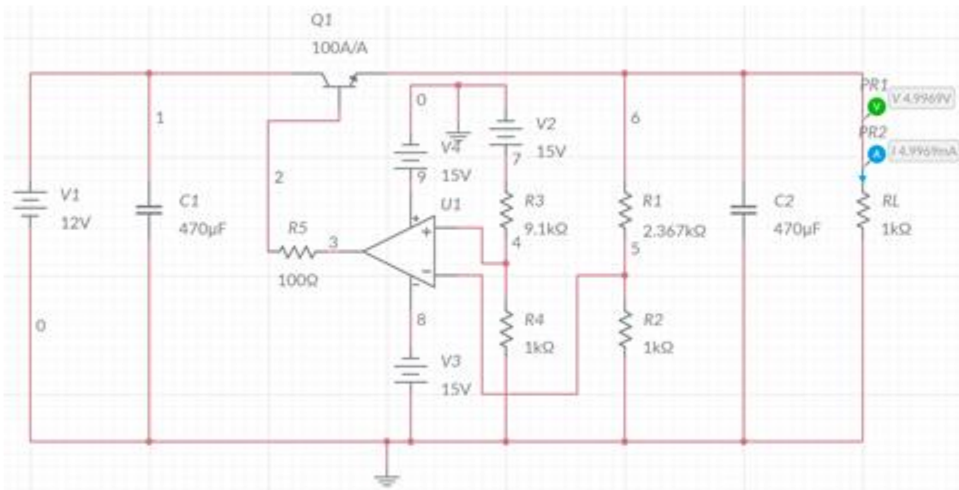


Figure 48: Designed 5V Linear Voltage Regulator

The regulated output voltage of 7V required for the prototype test that will be performed using the Arduino Nano Every board, will be designed following a similar approach as that presented in Section 3 of this document. Here, the LM7805 package will be adjusted to produce an adjusted regulated voltage of 7V. To do so, the resistances R1 and R2 must be calculated accordingly by knowing that the voltage between the output and the ground pins of the regulator, Vreg, is 5V for the LM7805 package. After performing the calculations, it can be determined that R1 is 0.4R2, so R1 can be set to 1.2kΩ and R2 to 3kΩ. In addition, it can be performed following a similar approach as done for the 3.3V and 5V voltage regulators shown in the previous two figures. However, the resistances of R1 and R2 must be changed accordingly to produce an output voltage of 7V. To do so, R1 must be set to 3.714kΩ, which will be varied on the testing environment due to availability constraints, and R2 must be set to 1kΩ. From the next figure, it can be observed that the output voltage was regulated to approximately 7V. This measurement will vary by a few milliamps due to the resistors and capacitor tolerances.

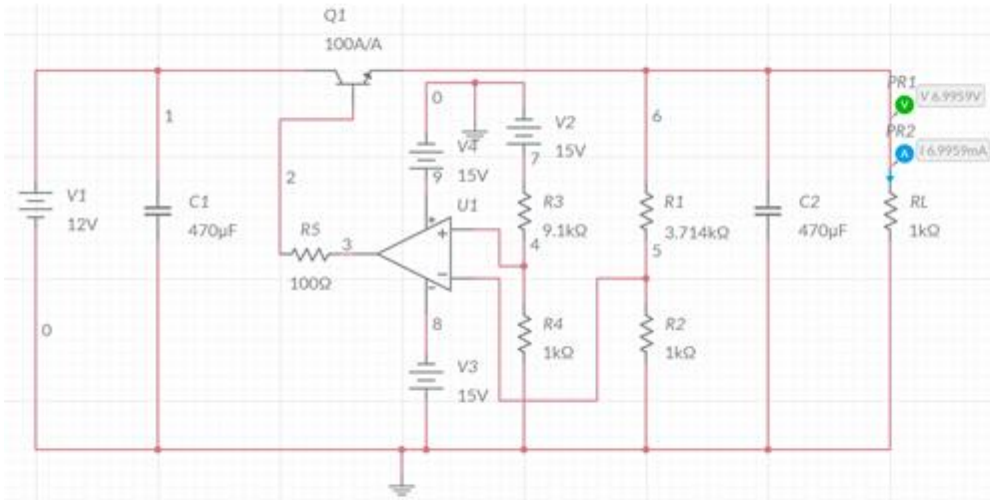


Figure 49: Designed 7V Linear Voltage Regulator

Each schematic for the simulated linear voltage regulator was included in this section to emphasize that based on the calculations, each required output voltage regulation was achieved.

5.10.2 Switching Voltage Regulators Designs

For the switching voltage regulators, a similar approach as followed for the linear voltage regulators will be performed in the design of the three different voltage regulations needed: 3.3V, 5V, and 7V. Even though the LM2576 packages come already with fixed output voltages of 3.3V and 5V, an adjustable design will be implemented following a similar approach as discussed in Section 3. However, the resistances for each case will be calculated and provided to test the designs and compare their behavior with the linear voltage regulator designs. For all the designs, the capacitor Cin will be set to 100µF, Cout will be set to 1000µF, and the inductor will be set to 100µH.

To regulate the output voltage to 3.3V, the resistances designated as R1 and R2 can be set to 1kΩ and 1.682kΩ, respectively. This is an ideal combination of resistances to produce an output of 3.3V. However, in the testing environment, such resistance is not available which will cause the output voltage to vary by a few milliamps. The behavior of this design will be tested and compared with the linear voltage regulator design. A circuit schematic for this design was generated using WEBENCH as shown in the figure below. This provides an idea of the implementation of this switching regulator in a testing environment.

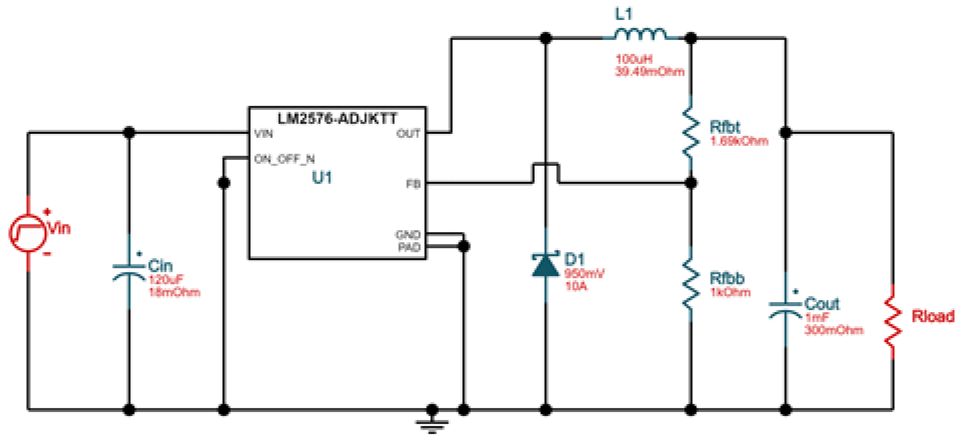


Figure 50: 3.3V Switching Voltage Regulator *(WEBENCH)*

To regulate the output voltage to 5V, the resistances designated as R1 and R2 can be set to 1kΩ and 3.065kΩ, respectively. This is an ideal combination of resistances to produce an output of 5V. However, in the testing environment, such resistance is not available which will cause the output voltage to vary by a few milliamps. The behavior of this design will be tested and compared with the linear voltage regulator design. A circuit schematic for this design was generated using WEBENCH as well. Its composition followed a similar approach as that shown in the previous figure. However, the resistance Rfbt was changed to 3.05kΩ, and the capacitor Cout was changes to 680µF. The schematic of this design can be found on the appendix of this document. This provides an idea of the implementation of this switching regulator in a testing environment.

To regulate the output voltage to 7V, the resistances designated as R1 and R2 can be set to 1kΩ and 4.691kΩ, respectively. This is an ideal combination of resistances to produce an output of 7V. However, in the testing environment, such resistance is not available which will cause the output voltage to vary by a few milliamps. The behavior of this design will be tested and compared with the linear voltage regulator design. A circuit schematic for this design was generated using WEBENCH as well. Its composition followed a similar approach as that shown in the previous figure. However, the resistance Rfbt was changed to 4.7kΩ, and the capacitor Cout was changes to 470µF. The schematic of this design can be found on the appendix of this document. This provides an idea of the implementation of this switching regulator in a testing environment.

5.10.3 WEBENCH DC/DC Convertors Designs

Another approach to regulate the voltage supplied by the battery is the DC/DC converter design generated by WEBENCH based on different parameters and specifications. With this software, different options can be considered. The generated circuit can be either balanced, of high efficiency, of low cost, or small footprint. Here, different designs will satisfy one or more of the characteristics mentioned before depending on the requirements and specifications of the project design. For our case, the design must have a small footprint since the dimensions of the overall design are limited to the electrical components' storage. However, all the characteristics mentioned are of equal importance for our design since we will strive to produce a balanced and highly efficient product that provides adequate dimensions at an affordable price. This is the primary goal of most designs today.

A similar approach as done with the linear and voltage regulators will be followed in the generation of different designs utilizing Texas Instrument WEBENCH Power Designer. Different output voltage regulations (3.3V, 5V, 7V) will be considered and the best design will be selected for testing.

For an output regulation of 3.3V, the following design was generated using WEBENCH. This design provides an efficiency of 89.8%, a BOM of $1.61, and a footprint of 275mm^2. It was customized to accept input voltages from 8V to 22V and regulate the output to 3.3V with a maximum current output of 3A.

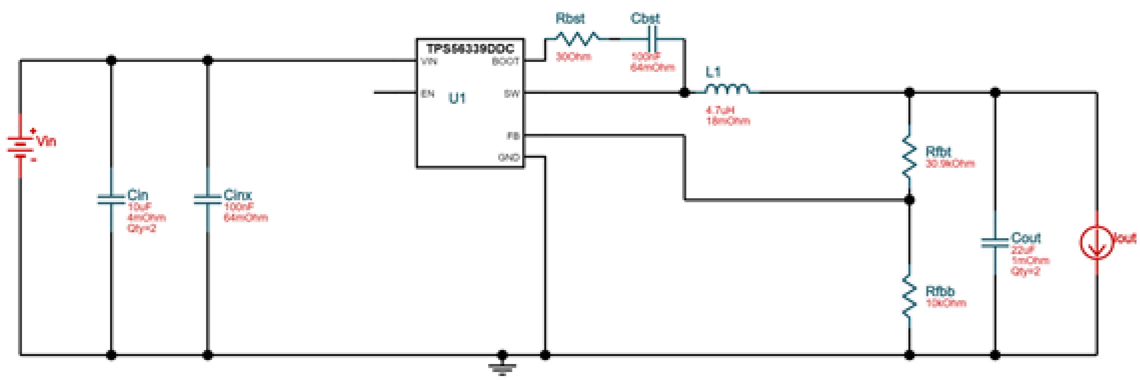


Figure 51: 3.3V Switching Voltage Regulator using TPS56339DDC *(WEBENCH)*

For an output regulation of 5V, a similar design to the one for an output regulation of 3.3V was generated using WEBENCH. This design provides an efficiency of 91.5%, a BOM of $1.70, and a footprint of 148mm^2. It was customized to accept input voltages from 8V to 22V and regulate the output to 5V with a maximum current output of 3A. However, the inductor was set to 5.6µH and Rfbt was set to 52.3kΩ. The design schematic will be added to the Appendix of this document to reference since the structure is similar to that presented on the previous figure.

For an output regulation of 7V, a similar design to the one for an output regulation of 3.3V was generated using WEBENCH. This design provides an efficiency of 94.3%, a BOM of $1.98, and a footprint of 334mm^2. It was customized to accept input voltages from 8V to 17V and regulate the output to 7V with a maximum current output of 3A. However, the inductor was set to 7.8µH and Rfbt was set to 76.8kΩ. The design schematic will be added to the Appendix of this document to reference since the structure is similar to that presented on the previous figure.

This type of design was chosen since it was able to regulate all the output voltages required and its composition and structure were easy to test on a breadboard. Also, it only has few elements which are easy to organize and implement on a PCB.

Once all the components for all the designed voltage regulators are obtained from different vendors, each design will be tested for its output voltage and current, and power efficiencies.

5.11 PCB Design

The PCB, or printed circuit board, is the power and data processing unit of this automated plant system. It is where the batteries, microcontroller, dc-dc converters, and Wi-Fi module are mounted. Its ISP (in-system programming) pins will be used to program the chip and sensors, and its power pins will power the motor, water pump, and sensors. Below is the team's initial PCB schematic and board layout. The software used to create them is EasyEDA because of its user-friendly interface, ability to import libraries from other PCB software such as Eagle and KiCAD, and its team collaboration capability.

The first step of PCB design is to choose and connect the components together, so the circuit operates as intended. This means researching and adding the correct PCB symbols for the desired components and connecting them based on their datasheets' specifications. When the PCB is generated, all the copper traces connect the correct components. The parts symbols and their footprints (how the parts will look on the PCB) were found through various sources such as the EasyEDA library, LCSC part libraries, and Autodesk Eagle part libraries which were imported into EasyEDA. The WiFi module, pin headers, and Qwiic ports came from the SparkFun library in Eagle, and the voltage regulators came from the LCSC part libraries. Then the components were connected together with wires using net flags, labels that match multiple pins with the same labels together. For example, pins with the label of SCL means that they are all connected to the SCL pin on the microcontroller. If a pin was not used, it was marked with an X. When the design is completed, the net list is checked, and the schematic is converted into a PCB. The entire schematic sheet is shown below in Figure X. This design is still in its preliminary stage as components such as the voltage regulators remain undecided.

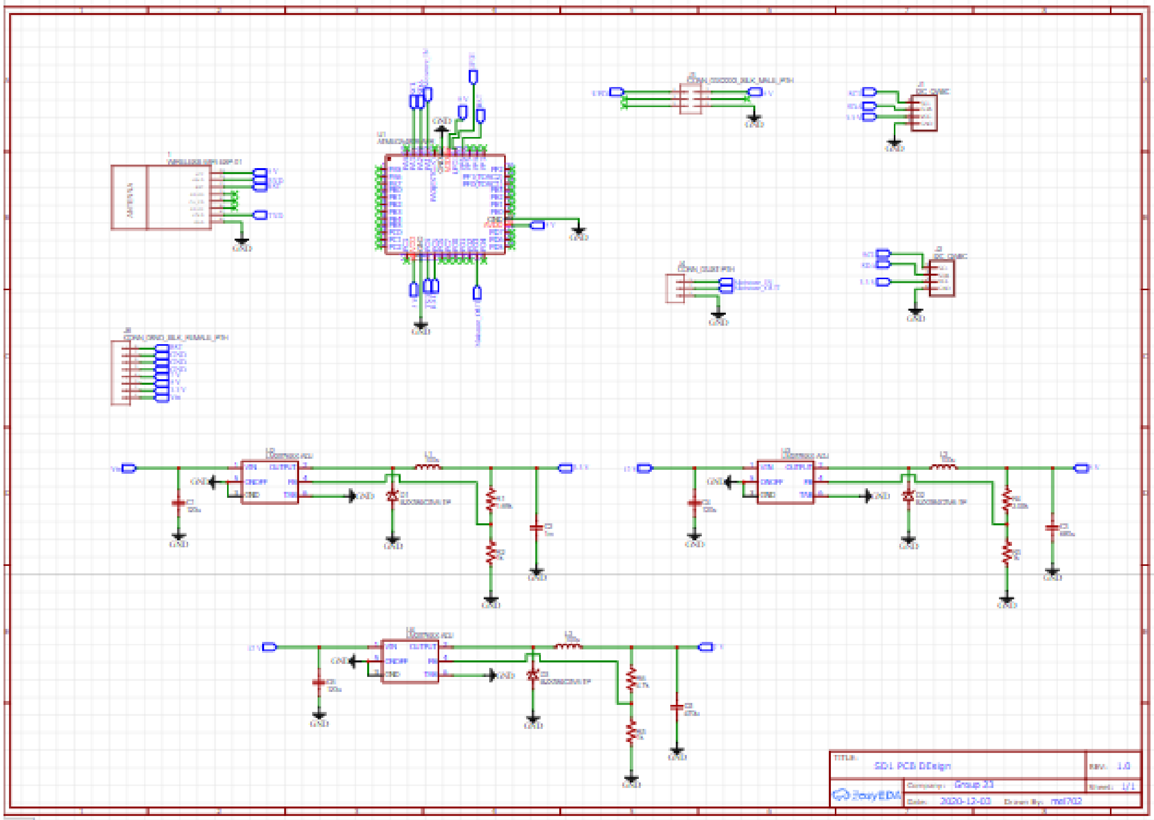


Figure 52: 3.3V Switching Voltage Regulator using TPS56339DDC *(WEBENCH)*

The 48-pin version of the ATMega4809 MCU can be seen in Figure X. It is the control unit of the entire circuit and is where most of the board’s components connect to. It is powered by the 5 V switching voltage regulator, and its other pins such as SCL, SDA, TXD, and RXD are labeled as well. The MCU and sensors datasheets were used in order to label their nets properly. Unused MCU pins are marked with an X.

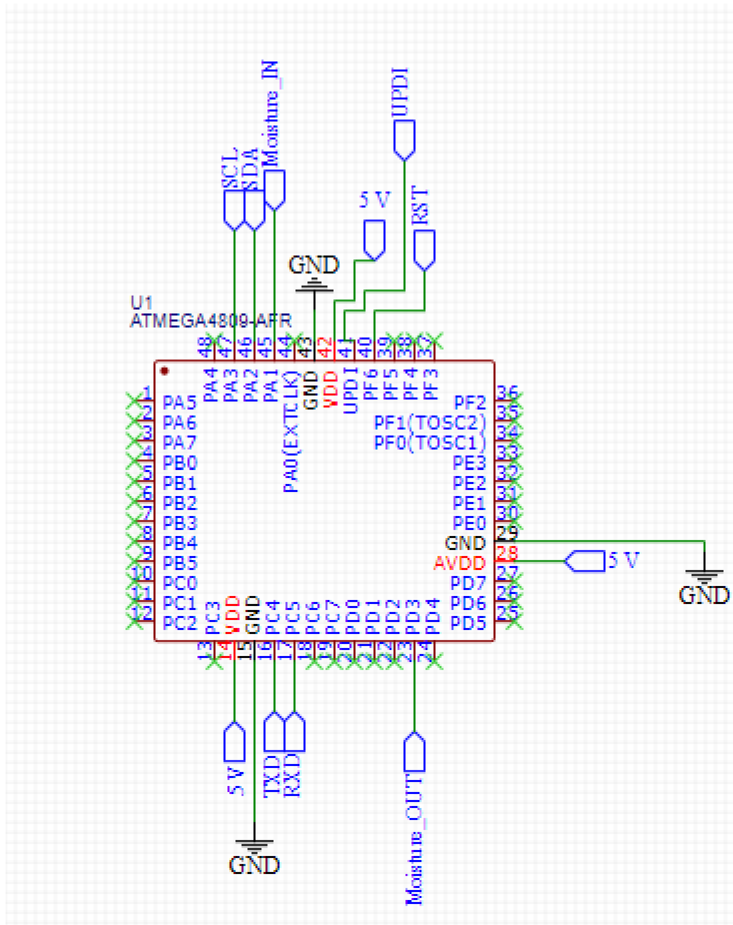


Figure 53: ATMega4809 Microcontroller

Below in figure X is the ESP8266 Wi-Fi module, which is soldered via through holes. It was connected based on the specifications given its data sheet. GPIO0, GPIO2, and CH_PD pins were not used, so they are marked with an X.

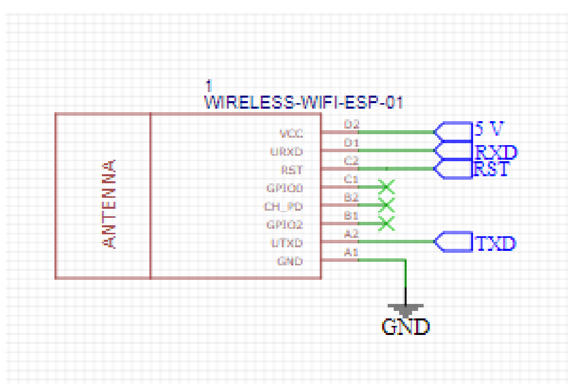


Figure 54: ESP8266 WiFi-Module

The pin headers are soldered via through holes and have metal connectors at each end, where one side is meant to be soldered into the board. Female headers are connected to the top end and are used to accept input from sensors or provide output to the motors. There are three pin headers in this design for voltage supply, UPDI programming, and moisture sensor. The voltage supply pins are there to power the motors and other external devices potentially in need of the regulator output. The UPDI pins are present to program the ATMega chip using the Atmel ICE probe ("Connecting Atmel ICE to a UPDI Target"); since it only needs 3 pins, the other 3 pins of the 3x2 pin header have X's. Lastly, the moisture sensor pins are used to communicate the sensor's output back to the microcontroller.

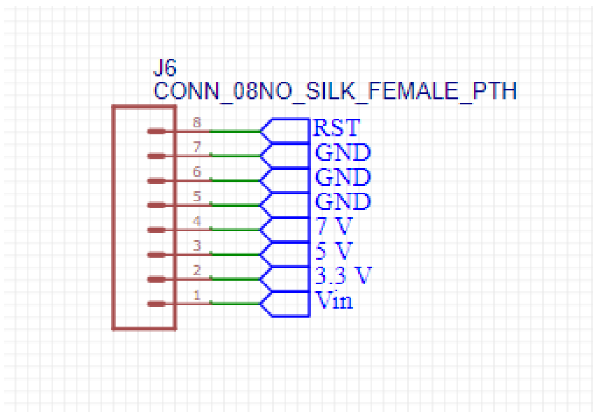


Figure 55: Voltage Supply Pin Header

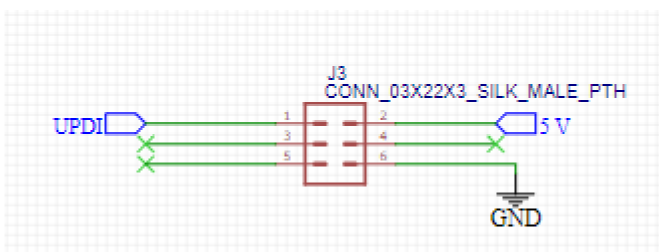


Figure 56: UPDI Programming Pin Header

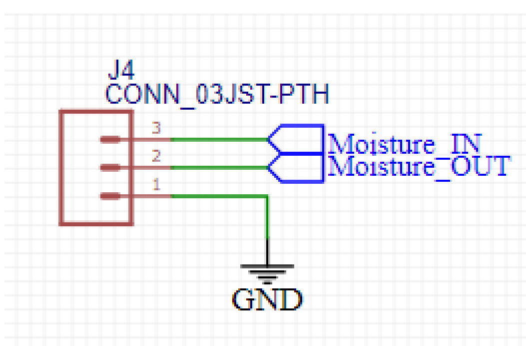


Figure 57: Moisture Pin Header

There are two Qwiic ports surface mounted on to the board. Qwiic ports, designed by SparkFun, are 4 pin JST connectors that connect to the I2C interface. These 4 pins are Vcc, Ground, SCL, and SDA ("Qwiic Connectors"). The temperature and light sensors in Figures X and X have Qwiic ports to connect to the MCU's SCL and SDA pins.

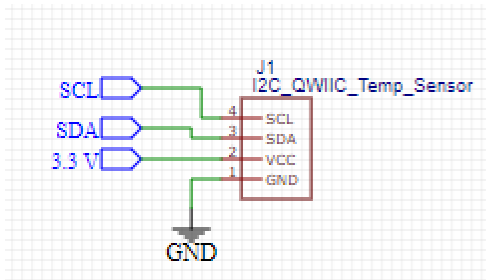


Figure 58: Qwiic Port for Temperature Sensor

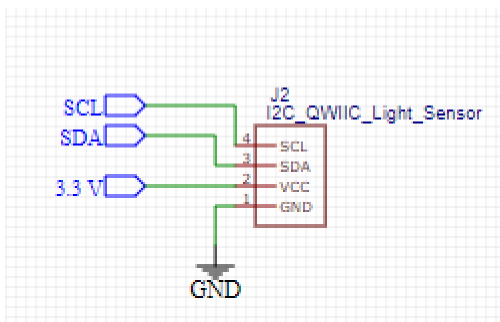


Figure 59: Qwiic Port for Light Sensor

While the team is still deciding on which type and model of voltage regulator to go forward with, they used surface mounted switching regulators in the schematic at the present time due to their prevalence in PCB designs. Switching regulator circuits in this project were based on those generated in TI Power Designer in the 5.10 Voltage Regulator section above. Switching regulators for 3.3 V, 5 V, and 7 V are shown in Figures X, X, and X respectively.

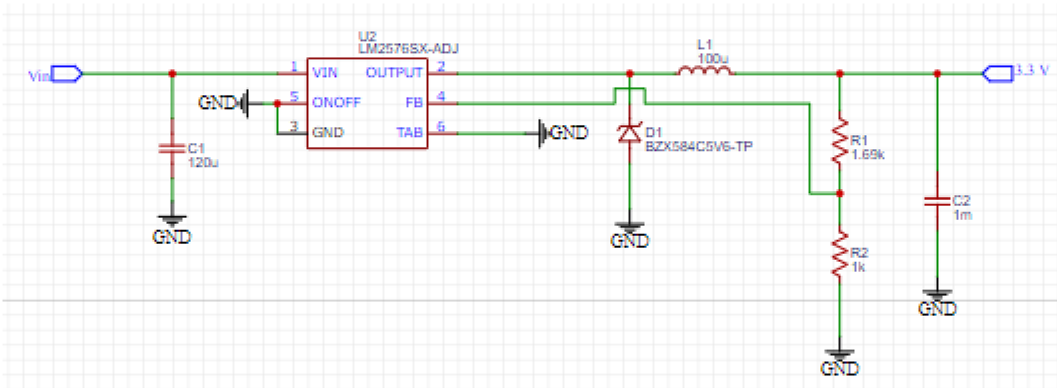


Figure 60: 3.3V Switching Voltage Regulator

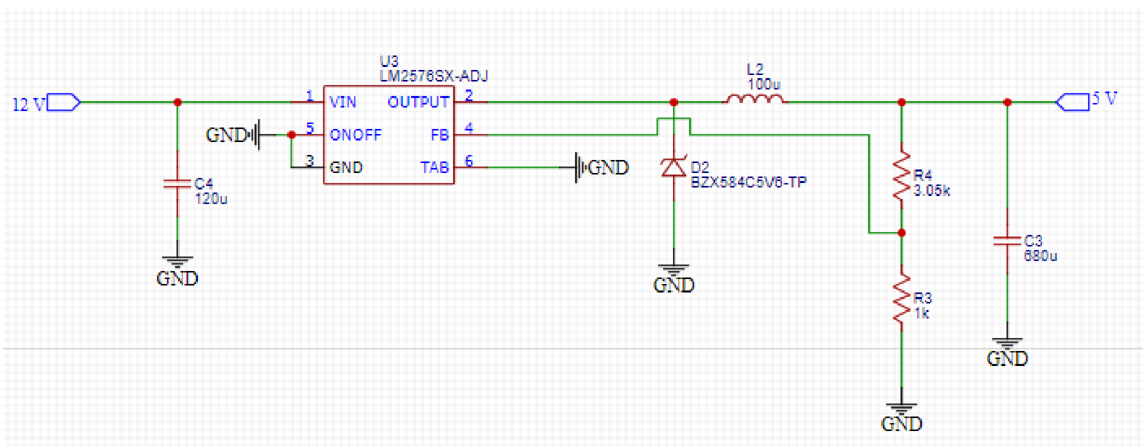


Figure 61: 5V Switching Voltage Regulator

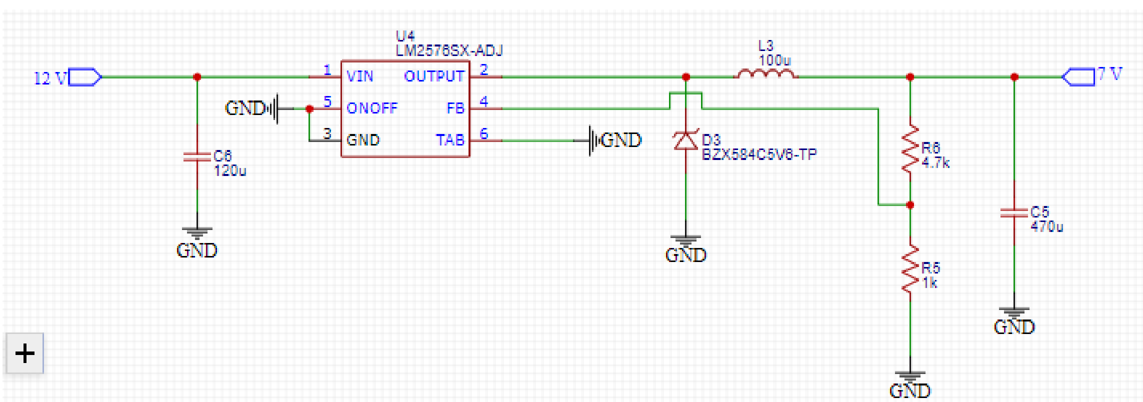


Figure 62: 7V Switching Voltage Regulator

The main types of components on the PCB are surface mounted and throughhole. The surface mounted components have pins at their sides that are meant to be soldered into the board’s pads. Through hole components have pins at their bottoms that are meant to be soldered into the board’s through holes. Each pin is connected to another via copper traces within the board's surface. The students generated the board in Figure X from the PCB schematic discussed above, placed the components within the board boundaries based on the relationship to each other, and autorouted their traces. Finally, they did a design route check (DRC) in order to ensure that there are no trace or hole errors (SF Uptown Maker, SparkFun). The 2D board is shown in Figure X while the 3D board is shown in Figure X. Table X contains the PCB specifications based on information provided by EasyEDA.

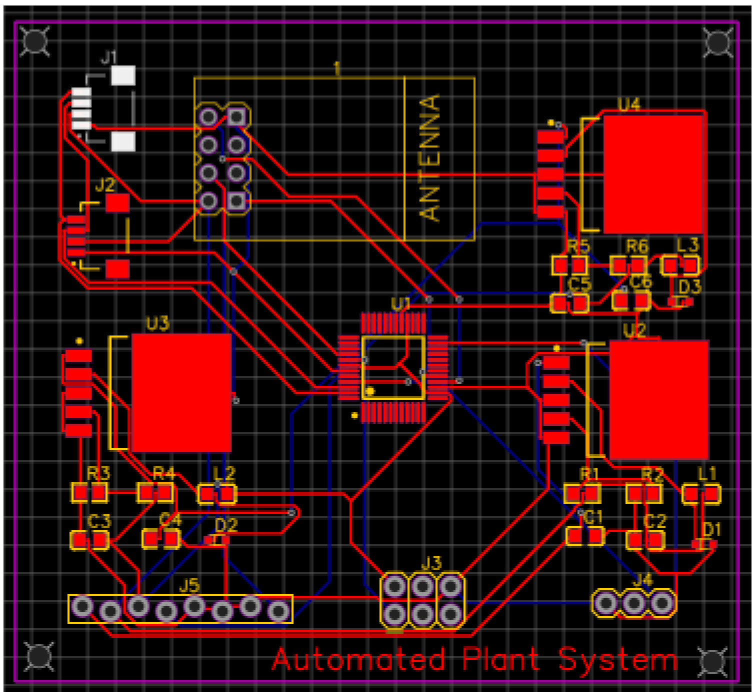


Figure 63: Senior Design 1 PCB 2D Board Layout

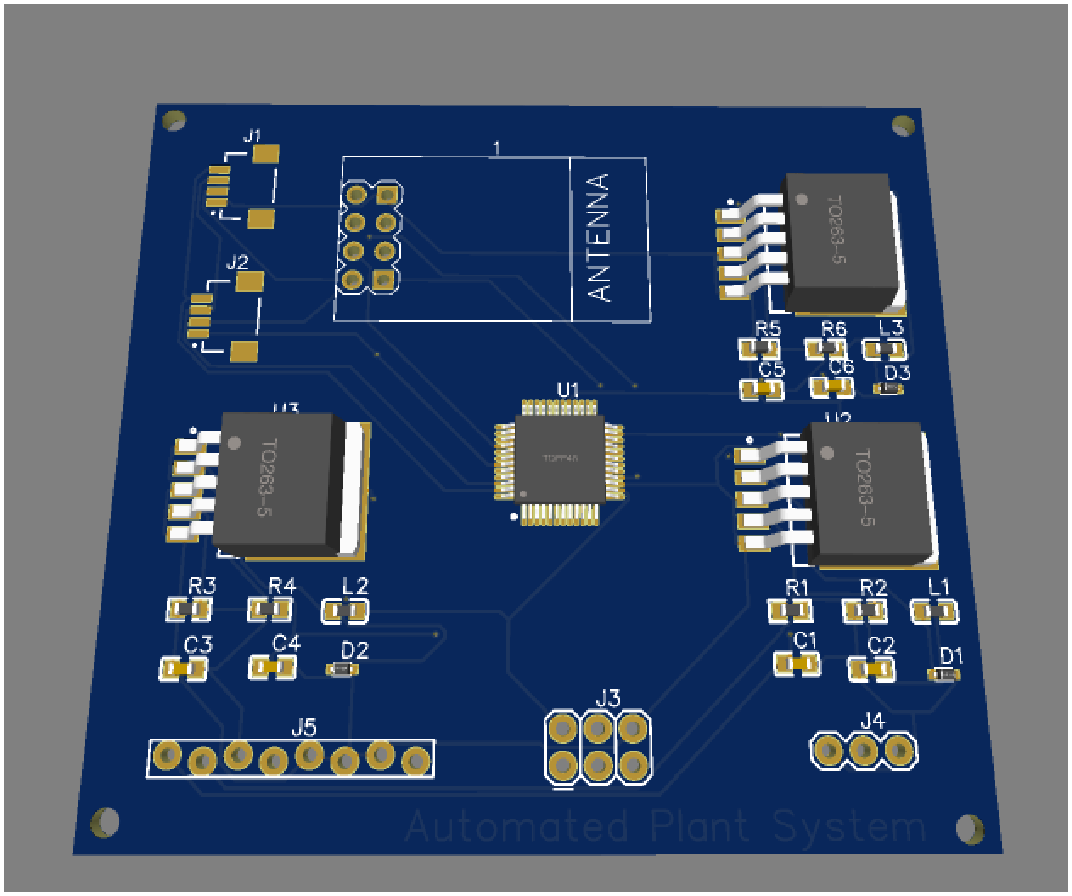


Figure 64: Senior Design 1 PCB 3D Board Layout

Board Size	65.53 mm x 59.82 mm
Number of Components	28
Layers	2
Pads	129
Holes	4
Vias	17
Nets	20
Routing Width	0.254 mm
Total Track Length	1277.78 mm

Table 12: PCB specifications

5.12 Flowcharts

The project consists of multiple systems running simultaneously all completing various necessary tasks. The systems each have their own responsibilities which are completed through the use of the components onboard. Their responsibilities cover a wide variety of aspects that are vital to a healthy plant including watering and providing the recommended amount of sunlight. When all work together, they provide an excellent form of care for the plant, assuring it gets all necessary nutrition for its survival.

The project consists of three mechanical systems – irrigation, shading, and rotational. These three systems are very different from one another, but each provide an important aspect of care. The systems have several pieces of equipment to help get their tasks done. To start, there are three types of sensors available for use, two light sensors, one temperature sensor, and one moisture sensor. The light sensors detect the amount of sunlight received by the plant at any given time. The temperature sensor provides the current temperature of the air surrounding the plant. The moisture sensor will be placed within the soil and will measure and report on how much water is present within the soil. These three input devices will provide all necessary data for determining the current state of the plant.

Along with the input components, the project consists of several output devices. To start, there will be a water pump which will be connected to tubes within the pot. This will allow water to be pumped into the pot with a simple command. The next is the shading device. This contraption is a combination of a folding fan and umbrella and, when sent the command, uses two motors to open and close and provide shade for the plant. Lastly, there will be a rotational device which consists of a circular plate that can rotate 180 degrees in both directions through the help of two motors. These outputs devices will be controlled by the microcontroller and will provide all necessary care for the plant.

A unique component of this project is that the devices within are not exclusive to individual systems. In fact, many of the components are shared among multiple systems. For example, the moisture sensor is utilized by both the irrigation and shading systems to both determine if the plant should be watered and if it is raining. This can cause discrepancies in operation and will be worked out during the programming phase.

One concern going into this project is how well the three individual systems will be able to work together. As stated above, many of the input and output devices are shared amongst the three systems. It is entirely possible that a command from one device will interfere with that of another. If multiple systems require the use of a component simultaneously, there is a possibility that one command could get lost or a glitch could occur. With all systems actively operating at all times, it is also possible to overload the microcontroller and cause an error in its output. This concern will be addressed in the program itself. The microcontroller will be programmed to process one command at a time. If multiple systems require its attention at simultaneously, the microcontroller will be able to put one command on hold and process the other. Once completed, it will address the second.

With this design, there is also the possibility that the microcontroller will not be able to store all pending commands ultimately resulting in the loss of one or more. Although possible, this scenario is unlikely. Given the simplicity of the potential commands as well as the capabilities of the microcontroller itself, there is very little chance of a backup. The commands themselves are rather simple and should be processed by the powerful microcontroller in a sufficient amount of time. For this reason, the concern can be written off as unlikely.

To gain a better understanding of the three systems, flowcharts were created. These flowcharts describe the software's operation and the components utilized. From the figure, it is possible to gain a complete understanding of the system's purpose as well as the tools used to implement its functionality. The decisions made by the microcontroller have been made visible as all possibilities have been shown. Now it is important to note that certain specifications have not been provided. For example, all flowcharts mention thresholds, but do not specify their values. This is because, at the time of writing, those thresholds have yet to be determined. As the testing stage of this project progresses, those threshold values will become more obvious and can be presented in the document. Until then, those values will be left out with the word "threshold" in their places.

It was decided that the best way to describe the software is to break it into three parts, each describing one of the systems. Each system has a unique functionality that uses a combination of the input and output components listed above. They all have their own decision trees that will be followed by the microcontroller when being addressed. While it is possible to create one tree that incorporates the software as a whole, it would be better to view them individually. That way, the flowchart will have a cleaner look and the processes will be easier to follow.

Three flowcharts have been created to describe the functionality of each of the systems. From these flowcharts, one will gain a better understanding of the system, its components, and its purpose. Each of the flowcharts have been provided in the sections to follow as well as a description of their functionality.

5.12.1 Irrigation System

The first system to be studied is the irrigation system. The purpose of this system is to provide water to the soil surrounding the plant when requested. It utilizes the moisture sensor as an input, the water pumps as an output, and a timer. Data regarding the watering schedule will be provided by the user through the application. Once sent to the microcontroller, those values will be converted to a corresponding watering schedule that will dictate the timing and amount of water received by the plant. This system follows a relatively straightforward operation that has been described in the flowchart below.

The irrigation system operation begins with polling the moisture sensor. Polling will occur every two minutes. The microcontroller will receive data from the sensor regarding the current moisture levels within the pot. This value will be compared to the threshold value that has been provided by the user and stored with the memory of the microcontroller. The threshold will be the minimum amount of water the sensor can detect before the plant should be watered again. The comparison will involve a simple subtraction operation with the sign of the resulting value dictating the next decision. If it is found that the measured value from the sensor is higher, that means that there is enough water within the pot and the plant should not be watered again. The timer will reset to two minutes and the system will hold until the timer goes off again at which point, the process will start again.

Alternatively, if the comparison results in the threshold being higher than the sensor, it can be concluded that the soil is too dry for the plant and should be watered again. The microcontroller will signal the water pumps to begin pumping water into the pot and will reset the timer to thirty seconds. Once the timer goes off, the microcontroller will turn off the water pumps and repoll the moisture sensor to determine whether the amount of water provided was enough. This is where the cycle restarts. It will continue so long as the product has power.

There is one unknown value within this flowchart that will be entirely dependent on the plant itself. This is the threshold for the moisture level. The moisture level threshold will be determined by the amount of water the plant should receive on a daily basis which in turn will vary depending on the plant within the system. The daily water level will be provided by the user and converted to a threshold value by the microcontroller. The threshold value can cover a wide variety of numbers and will be used for the irrigation system functionality. Due to the variability of this value, it has not been provided in the flowchart. Instead, the word "threshold" took its place showing where that value will be used. During operation, this value of course will take its place within the flowchart.

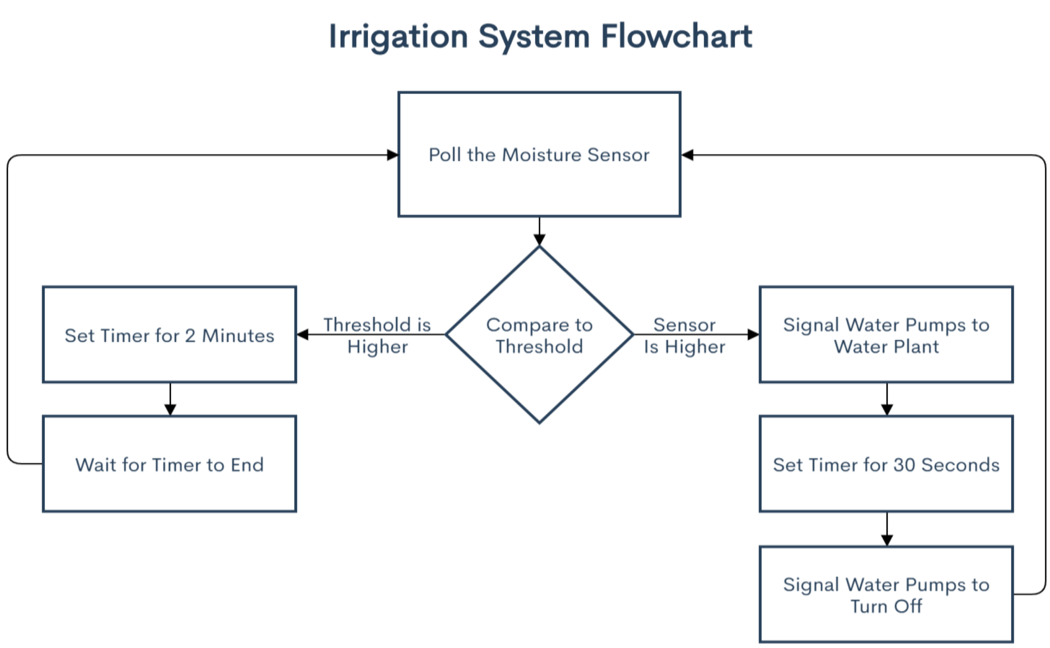


Figure 65: Irrigation Flowchart

5.12.2 Shading System

The second system is the shading system. This is by far the most complicated of the three as it involved the usage of all three sensor types as well as the shading device. In terms of operation, there are two sides to its functionality. First, there is the portion responsible for monitoring the amount of sunlight received by the plant. This side utilizes the temperature and light sensors as inputs, the shading mechanism as an output, and a timer. This portion will use the measured values from the light sensor to determine how much sunlight the plant has received. After reaching its threshold, it will activate the shading system until the next day. The system will also utilize the temperature sensor to measure the temperature of the air surrounding the plant and in turn, determine whether the plant is too hot. If the plant is hotter than it should be, the shading mechanism will be activated for a shorter period of time to allow the plant a chance to cool off.

The cycle begins by polling the light sensors. This will allow the microcontroller to determine how much sunlight the plant is receiving at any given time. Two light sensors will be used in this project so two values will be received. The higher of the two values is the largest amount of sunlight the plant is receiving and should be used over the other. A simple subtraction operation will be performed on the two values to determine which is higher. Whichever is higher will be added to a new variable that will keep track of the total sunlight received within a day. This total will then be compared to the threshold which was preset by the user. The threshold will represent the highest amount of sunlight the plant can receive in one day. If the total is higher than the threshold or they are equal, the plant has received at least the maximum amount of sunlight for the day and should be protected from it going forward. The microcontroller will send a signal to one of the motors controlling the shading mechanism, requesting it to open the shading system above the plant and set a timer for ten hours or 600 minutes. No matter the time of day when the initial covering occurred, the shading system will not close until sometime within the day or at least the night prior. This will assure that the plant does not receive additional sunlight until the following day. Before going back to low power mode, the microcontroller will reset the total variable. The current day has already concluded and there is no need to continue to keep track of the light received. For this reason, the total count will reset to prepare for the next day’s work.

If the comparison with the threshold results in the threshold being higher than the total value, the microcontroller will conclude that the plant has not received its daily dose of sunlight and will not open the shading system. Instead, it will move on to checking the temperature of the plant. The microcontroller will poll the temperature sensor to determine the temperature of the air surrounding it. This value will be compared with the threshold which represents the highest temperature the plant can be before being considered too hot and has been preset by the user and depending on the type of plant utilized. If the threshold is higher, the plant is not too hot. The timer will be set to five minutes and the system will remain in idle waiting for it to go off. At this point, the process will reset with the initial polling of the light sensors.

If it is found that the value from the temperature sensor is greater than or equal to the threshold, it will be concluded that the plant is too hot. The microcontroller will signal the shading system to open, providing shade to the plant and allowing it to cool off. The timer will be set for sixty minutes which should provide a sufficient amount of time for the temperature to lower. Once that timer goes off, the microcontroller will signal the other shading mechanism motor to close the shading system. The process will reset and the microcontroller will once again poll the light sensors.

As stated above, the shading system also has a second functionality. It is not only responsible for the amount of sunlight received but also for protecting the plant from excessive rain. One of the intended features of the project is to determine if excess rain is occurring and to protect the plant from flooding. If it is determined that there is too much rain, the shading system should be activated. This whole procedure can be seen in the flowchart below. When the device is initially turned on, the moisture sensor will be polled, and the timer will be set for two minutes. After the timer goes off, the moisture sensor will be polled again. This value will be compared to the previous measurement. The difference between the two will be found using the subtraction operation. That difference will then be compared to a preset threshold value using the same operation. If the threshold is higher, it can be concluded that it is not raining, and the process will reset. If the difference is higher, it can be concluded that it is raining excessively, and that the shading system should be implemented. The microcontroller will send a signal to the shading system to open it and set a timer for thirty minutes. Once the timer goes off, the microcontroller will signal the other shading system motor to close the mechanism and the process will reset. This will assure that the plant is protected from drowning due to excess rain.

With the large workload associated with these responsibilities, there is the ever-present concern of the system becoming overwhelmed. This may occur when both functionalities require the attention of the microcontroller at once. This can lead to a wide variety of outcomes including delayed response time, loss of code, or ever entire system crashing. Despite the fact that these consequences are possible, they are highly unlikely to occur. Like stated above, many aspects of this project are rather simple. The procedures required for all systems have very low complexity and will require few lines of code to correctly implement. The microcontroller operates at a fairly quick speed and should be able to successfully process all lines of code in a timely manner leaving little time for backup. Therefore, this issue does not pose a concern for the successful implementation of this project.

Another concern present in this system is the direction of rotation of the shading mechanism. The umbrella structure itself does not have the capability to rotate past a certain point in either direction. If the microcontroller were to signal the device to open while it is already open, this may cause the mechanism to rotate past its limits and break. To assure this does not occur, a state variable will be utilized in the code. This will keep track of the current state of the shading mechanism. As soon as the shading mechanism is opened, this variable will be set to one. Once the microcontroller sends the closing signal, it will change that same variable to zero. All functions written involving the shading mechanism will first check the state of said variable and use that to determine which path to follow. If the microcontroller requires the device to be opened but finds that it already is, the code will allow it to terminate this notion before sending an unnecessary command. The same goes for closing the device. This state variable will play an important role in ensuring the proper use of the equipment and its structural integrity.

The last aspect to address is the moisture sensor and its presence in both the irrigation and shading systems. This particular fact has the potential to cause problems with the software. There is the possibility that both systems will require the use of the sensor at once which can cause the microcontroller to become overwhelmed as it is unsure of how to respond to both. Like the previous concern, this can lead to numerous issues like loss of code of crashing of the system. The moisture sensor issue will be addressed in the code itself. For one, both systems will require the sensor to be sampled at the rate – two minutes which means that both systems will share the same timer. Once the timer goes off, the data from the moisture sensor will be used to check both the moisture level for the irrigation system as well as the presence of rain for the shading system. Because there are no time requirements for the shading system's functionality, it is perfectly fine for it to sample at the same, uneven rate as the irrigation system. This will allow for a more efficient system that does not overwhelm the microcontroller.

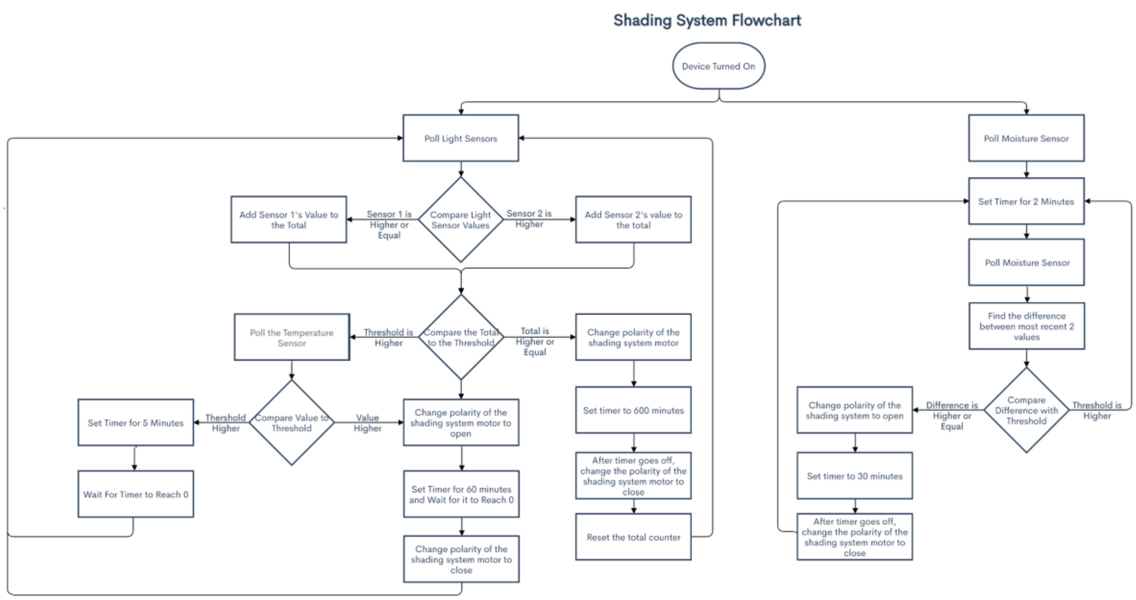


Figure 66: Shading System Flowchart

5.12.3 Rotational System

The last system within the project is the rotational system. This is responsible for rotating the plant on an axis every so often to assure that the plant receives an equal amount of lighting on all sides and grows in an upward direction. This requirement is implemented using a timer and the rotational plate as the output. Being the only system without any input devices besides the timer, it is the simplest and the easiest to implement with the project. Once given the signal by the microcontroller, the plate will rotate one hundred and eighty degrees in a particular direction. The direction of travel changes with each rotation depending on the state variable.

This system starts when the timer hits zero. Initially, the timer will be at zero as the product will have just powered on. The microcontroller will then determine the state of the rotational plate using the state variable. Depending on the state, the microcontroller will signal the plate to rotate in a particular direction for a certain period of time that will result in the plant rotating one hundred and eighty degrees. The microcontroller will then change the value of the state variable and reset the timer for twenty minutes and remain idle until the clock hits zero. This is when the cycle restarts. It is a rather simple system compared to the other two but is incredibly effective in caring for the plant.

The amount of time between rotations can vary greatly. This value will be preset by the programmer and will not be customizable by the user as rotation times are not vital to the survival of the plant. However, there is a lot of room for adjustment for the programmer. There are many advantages and disadvantages to using longer and shorter rotational times. A shorter time will allow the plant to rotate more frequently which assures a more equal light distribution for all sides of the plant. However, this particular method will use up a lot of power. If a longer rotational time is used, the system will be more power efficient, however, there is a higher probability of uneven lighting. In order to balance the two sides, a value in the middle should be selected. At the time of writing, a rotational time of twenty minutes seemed to be the best option. While this duration has the possibility of causing uneven light distribution, it is unlikely. There is a slim chance that the weather will change that rapidly. The duration, however, is longer than others which will assure the most efficient power system possible. This is ideal as it will cut down on the operation cost of the product and assure a longer battery life.

One concern arises with this design. While the plant itself will be rotating every twenty minutes, not all systems on board will be following that same pattern. In fact, many of the components, like the water pumps and the tubes associated with them, will be mounted to both the rotating and non-rotating portions of the design. If the pot were to rotate too far in one direction, the tubes can tangle and will eventually lead to the product breaking. To assure that this does not happen, the rotational system has been equipped with two motors – one is either direction. They both will be responsible for rotating the system in either direction and will be commanded by the microcontroller accordingly. To assure that the microcontroller is fully aware of the current state of the rotational plate and does not accidentally command it to rotate in the wrong direction, a state variable will be used. The state variable will keep track of the position of the plate by its current value. To ensure its integrity, the state variable will be changed to the opposite value immediately following the rotation of the plate. Prior to sending a command to the system, the microcontroller will be required to check the status of said variable. This will assure that the plate is not accidentally rotated in the wrong direction and will increase the durability of the project.

An additional function can be implemented with this system. While the sun is set, the plant will not be receiving any sunlight. During this time, there is little use for the rotational system itself. Therefore, the system should be deactivated during these dark hours. This can easily be implemented using the light sensors. An additional line of code as well as a threshold would be needed to implement this functionality. Prior to checking the status of the state variable, the light sensors would be polled to determine the amount of light currently shining on the plant. A predetermined threshold will be set to indicate when it is safe to assume that the Sun has set for the night. Once the measured values from both light sensors fall below that value, the microcontroller will assume that the Sun has set and will stop utilizing the rotational system. It will instead reset the timer for an hour and recheck the light sensors once that timer goes off. This process will continue until one of the light sensors reports a value above the threshold which will signal that the Sun has risen once again. At this point, the microcontroller will bump back into its original cycle, rotating the plant every twenty minutes and will continue until the Sun sets once again.

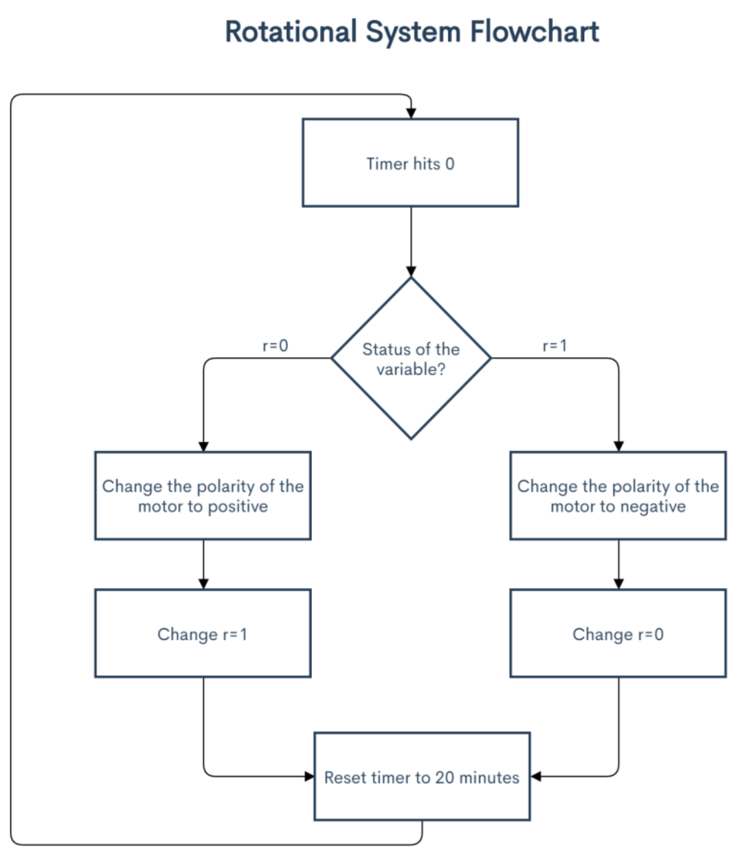


Figure 67: Rotational System Flowchart

6.0 Integration and Testing

This section discusses the integration and testing of the design, components, and final project as a whole. Here, we will dive into the steps that went into transforming the initial idea into a fully functioning end product. Like all new designs, the final product was not implemented on the first try. In fact, it took numerous tests and countless tweaks to assure all components and features worked exactly as they should. The issues were identified during the testing stage. Here, all components were tested individually and as a whole to assure they were able to function as intended and meet all project requirements.

6.1 Voltage Division

The first system that was tested was WaveForms2015, the software associated with the Analog Discovery 2. At the beginning of the semester, the group was given a developmental kit to assist with testing the components. This kit was designed by Digilent and utilizes the Analog 2 Discovery. This device pairs with a piece of software called Waveforms. Prior to this project, none of the group members had worked with this software and therefore a learning curve was present. For this reason, the first test was a simple circuit. This would allow the designers to gain a basic understanding of the software and assure later testing goes smoother.

For this test, a basic circuit was designed. Two resistors were connected in series with a voltage source. The Analog 2 Discovery was used as an oscilloscope and measured the voltage across both resistors. The measured values were displayed on the laptop and can be seen below. The results clearly displayed the concept of voltage division as the two measured values added up to that of the voltage source.

Figure 68: Analog Discovery 2 Setup

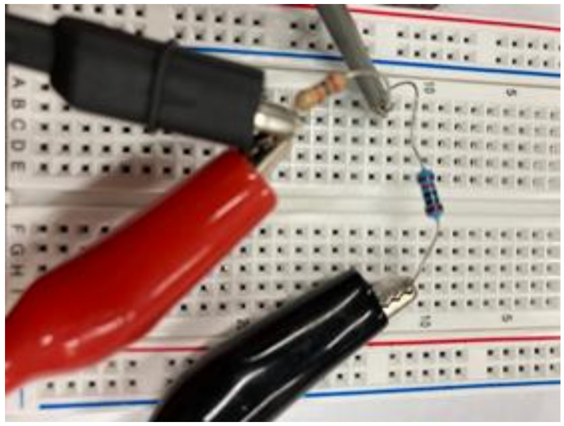


Figure 69: Voltage Division Circuit

Figure 70: Voltage Across Resistor 1

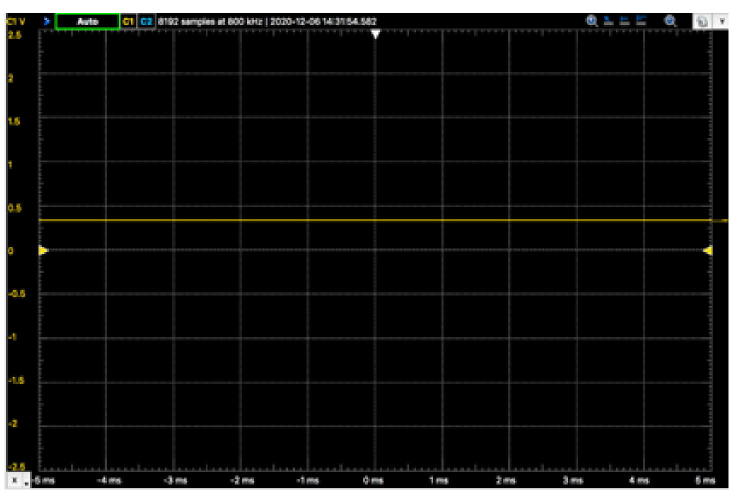


Figure 71: Voltage Across Resistor 2

6.2 Voltage Regulator

The second test utilized a voltage regulator to test the equipment's ability to regulate voltage. For this one, a battery was used as the input voltage, two capacitors were used to maintain DC voltage, and of course the voltage regulator circuit. The voltage was measured at the output of the voltage regulator with the oscilloscope and the results displayed on the computer. With this the user was able to verify that the voltage can be successfully regulated. This will be used along with resistors in the final product to produce a steady voltage at the correct value for the components.

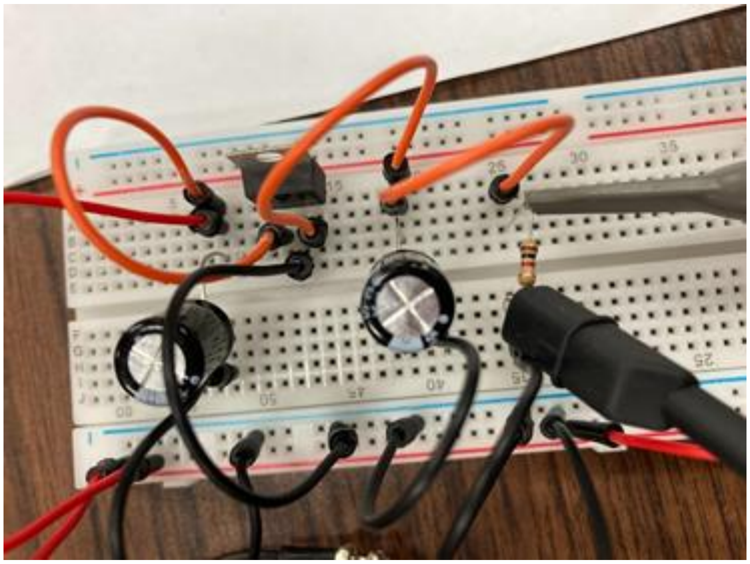


Figure 72: Linear Voltage Regulator Circuit

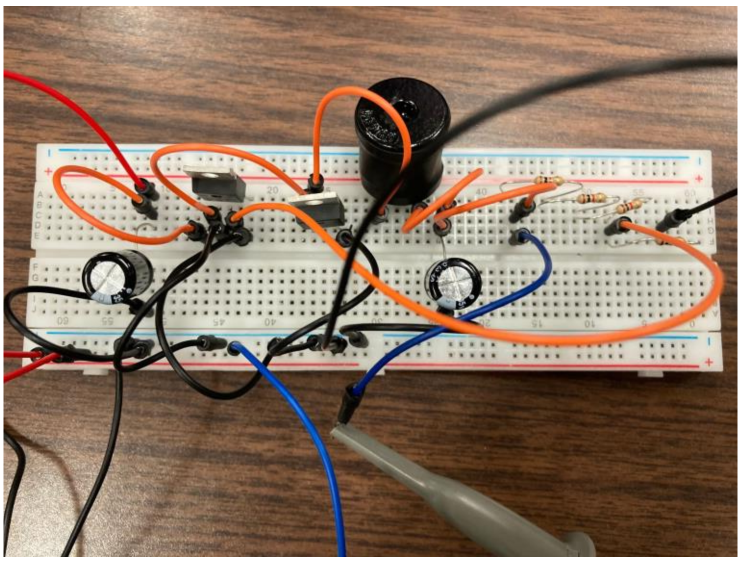


Figure 73: Switching Voltage Regulator Circuit

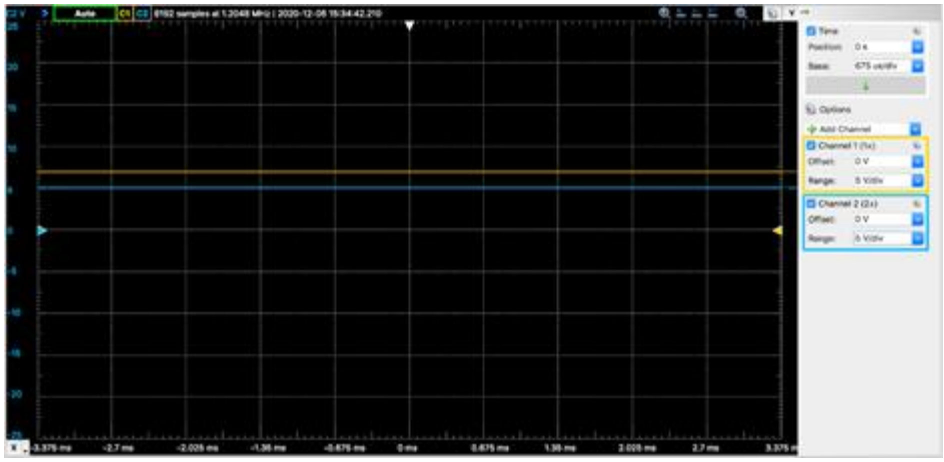


Figure 74: Voltage Measurements at Voltage Regulator Output

6.3 Microcontroller

The microcontroller plays an important role in the project. It is the brain of the entire system, sending signals to the various components to gain a better understanding of the plant status as well as to send care when needed. It is very important that the microcontroller functions properly. Without it, there would be no way for the components to work together and in turn, no project.

Because the microcontroller will be utilized in tandem with the sensors, it seemed only fitting for it to be tested alongside them in this stage. For each of the sensor tests specified below, the microcontroller was utilized. The sensor would be connected to the microcontroller which was then connected to the computer for testing. Because the sensor tests all came back successful and the sensors relied heavily on the microcontroller, it can be assumed that the microcontroller works. This was how the microcontroller was tested for the testing stage.

6.4 Moisture Sensor

Another major aspect of this project is the sensors. The sensors provide inputs to the microcontroller which in turn allows it to make decisions about the plant's care. It was important to test at least one of these sensors to ensure that it works as well as give the designers experience using it. Here, the moisture sensor was tested. The moisture sensor is responsible for measuring the amount of moisture in the soil and send that data to the microcontroller. To test the functionality of the sensor, the moisture sensor was connected to an input voltage of 3.3V and then directly to the oscilloscope. Because the sensor has yet to be fully calibrated and the levels not determined, connecting the sensor to the microcontroller will not result in an accurate reading and therefore, this test could not be conducted. Despite that, the device was still connected to the oscilloscope and the results displayed on the screen. These results can be seen below.

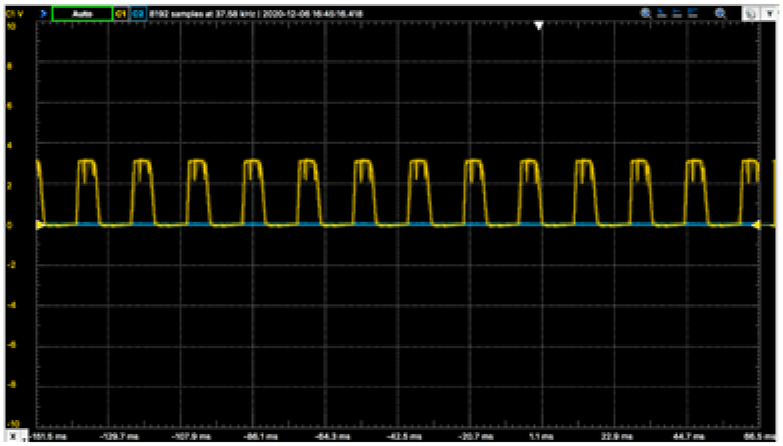


Figure 75: Moisture Sensor Oscilloscope Results

6.5 Temperature Sensor

The second sensor is the temperature sensor. This is responsible for measuring the temperature of the air surrounding the plant and will provide data to the microcontroller for analysis. The temperature sensor will be tested to ensure that it is able to detect valid readings. For this, the sensor will be connected along with the microcontroller to a breadboard, a 3.3V power source, and then to the computer through a micro-USB cord. A short code written in Arduino IDe will allow the microcontroller to analyze the value measured by the sensor and display it on the screen. Unfortunately, this test was not completed prior to this paper's submission. All attempts lead to faulty readings or technical errors. The test will be conducted again on a different computer and with different versions of the two components to assure that the problem was not caused by software or compatibility. For this reason, no data has been provided on the outcome of this test.

6.6 Light Sensor

The third and final sensor to be tested is the light sensor. This component is responsible for detecting the level of sunlight surrounding the plant at the request of the microcontroller. For this test, one of the light sensors was utilized. It was connected to the software and various readings were measured. Initially, the sensor was connected directly to the board and was tested on its own. However, this was unsuccessful as the sensor communicates through I2C and needs another device to translate for it. The second test involved connecting the light sensor to one of the microcontrollers which was then connected to the computer itself for reading. This turned out to be successful as a reading was displayed on the screen.

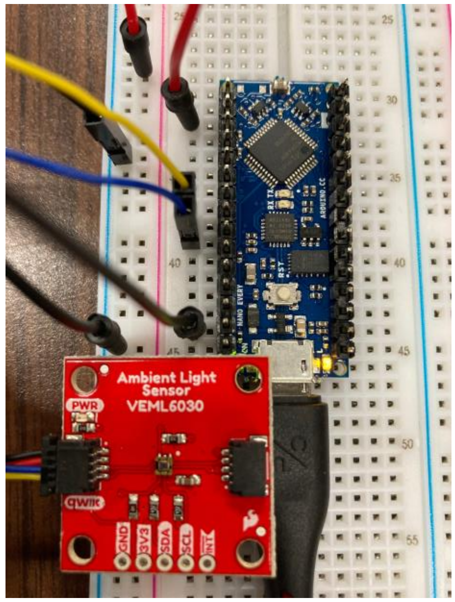


Figure 76: Light Sensor Circuit

6.7 Motor

The last component that was tested was the motor that will be used with the shading system. This motor will be placed at the top of the umbrella-like structure and will allow it to fold and unfold when commanded to do so. This motor must create enough force to control the devices without potentially breaking the device or hurting the user. The motor will be tested by connecting a 12V voltage source to the motor and seeing if it spins. Unfortunately, the group was unable to secure a 12V power source before submitting the paper and therefore, was not able to complete this test. As soon as a 12V power source is in the group's possession, the test will be completed.

7.0 Administrative Content

In this section, the milestones for both courses, Senior Design I and Senior Design II, will be discussed along with the brief overview of the team's schedule and progress, the budget of the project, different project design problems, project roles, and future improvements of the proposed design.

7.1 Overview

The team meets twice a week (Tuesdays and Thursdays) to discuss project progress. Occasionally they arrange meetings for off days to make further progress on the project if necessary. Members ask questions of other members if they are stuck on an issue of research and documentation standards, and the team works on documentation sections that require the input of all team members. In addition, the team members look over the other members research to make sure it is free of errors and has no missing information. Otherwise, the team members look into and write about their own areas of research individually. The first few weeks were spent on project idea generation and rudimentary exploration of the parts and technical knowledge needed for each idea. Once the automated plant system idea was selected, each team member was assigned a section of the design to develop. Each did research into the background of their system and the parts required for it and added that information to the project documentation. In addition, a 3D CAD design, schematic of the electrical systems, and a basic PCB design of the expected finish product is presented in the design section. Finally, the team ordered the parts and tested them to make sure they acted as required and connected as expected.

7.2 Milestones

The milestones for both Senior Design I and Senior Design II are discussed in this section based on given completion dates and tentative dates for the design and implementation of the overall proposed design.

7.2.1 Senior Design I Milestones

The milestones to be completed in Senior Design I are described below in Table 6 along with their completion date and status.

Senior Design I		
Activity	**Date**	**Status**
I. Ideas	8/28/2020	Completed
II. Project Selection and Role Assignment	9/15/2020	Completed
III. Project Report		
1. Divide and Conquer 1.0	9/18/2020	Completed
2. Divide and Conquer 2.0	10/2/2020	Completed
3. 60-page Draft Documentation	11/13/2020	Completed
4. 100-page Report	11/27/2020	Completed
5. Final Documentation	12/8/2020	Completed
IV. Research, Documentation and Design		
1. Light Sensor	12/8/2020	Completed
2. Temperature Sensor	12/8/2020	Completed
3. Moisture Sensor	12/8/2020	Completed
4. WiFi/Bluetooth Module	12/8/2020	Completed
5. Solar Panel	12/8/2020	Completed
6. Power Supply System	12/8/2020	Completed
7. Rotation System	12/8/2020	Completed
8. Shading System	12/8/2020	Completed
9. Irrigation System	12/8/2020	Completed
10. Microcontroller	12/8/2020	Completed
11. PCB Layout	12/8/2020	Completed
12. App	12/8/2020	Completed

Table 13: Senior Design I Project Milestones

7.2.2 Senior Design II Milestones

The milestones to be completed in Senior Design II are described below in Table 13 along with their completion date and current status. The team will start ordering parts on the week of November 29th, and the prototyping will begin during winter break.

Senior Design II		
Activity	**Date**	**Status**
1. Part Orders	11/29/2020	In Progress
2. Build Prototype	4 weeks	-
3. Testing and Redesign	2 weeks	-
4. Finalize Prototype	2 weeks	-
5. Peer Presentation	TBA	-
6. Final Report	TBA	-
7. Final Presentation	TBA	-

Table 14: Senior Design II Project Milestones

7.3 Budget

In this section, an estimated budget to cost the design and implementation of the entire proposed design is discussed in Table 14 below. The team needs to purchase three copies of most components excluding a few physical ones that are not likely to break during construction. Featured below is an estimate of the current budgeted price for different components.

Section	**Cost**
Plant System	$10
Irrigation System	$60
Light Sensor	$15
Moisture Sensor	$20
Temperature Sensor	$17
WiFi/Bluetooth Module	$20
Rotation System	$30
Shading System	$50
Microcontroller Kit	$80
Power System (including Battery)	$50
Solar Panel	$30
Software Development	$0
PCB	$20
Total	$405

Table 15: Project Cost Breakdown

The plant system includes the grown plant, pot, and soil and fertilization materials. The irrigation system would consist of mini plastic piping, water container, sprinkler, and hose. The sensors, WiFi/Bluetooth module, and solar panel can be purchased in whole at popular electronics supply stores. The rotation system would consist of a plate stand underneath the plant pot and a servo motor controlling its spin. The shading system would consist of curved, connected sheet metal pieces that mechanically spread out to cover the plant. The microcontroller kit consists of an Arduino Nano Every board for prototyping, ATMega4809 microcontroller IC for final design, and an AVR ISP (In-System Programming) to program the IC. The power system includes two battery holders with rechargeable and non-rechargeable batteries respectively and voltage regulator circuits on PCB(s). This PCB is wired to systems, sensors, and a microcontroller to power them. The software application platform (Adobe XD) is normally $10 a month, but it is $0 due to a university subscription.

The total cost is estimated to be $405, more $1595 less than the team's $2000 budget. Therefore, the team would have the resources to easily replace or rebuild non-working components and remain within budget.

7.4 Project Design Problems

When it comes to the mechanical aspect of this project, there are several problems that may present themselves. The first and foremost area of concern with the mechanical systems of this project is the shading system. The main reason that problems may arise with this system is that there are many mechanical requirements that all are at odds with each other and finding the perfect balance for an electrical engineer may prove difficult. For an example, we want the shading system to be larger than the plant by a good margin so that the plant may be completely shaded, but this requirement makes the weight of the system significantly increase. Also, the larger the shading system, the harder time the material will have supporting itself, considering it's all supposed to branch from one center point. One solution to structural issues is to use stronger materials, like steel, however these materials have their own weight issues. Another issue with the weight of materials is that we intend to install a motor that will be able to fold the shading fixture. If these materials are too heavy, then we will need a larger motor, and with a larger motor, the power requirements may be larger than that reasonably provided from the power supply. The way in which we hope to combat these potential issues, is by using a hybrid of stronger materials, and weaker materials. For instance, we hope to make our covering out of a combination of steel pieces for support, and canvas for its lightweight and coverage.

7.5 Project Roles

The group is composed of four Electrical Engineering Major students. Each has a strength in different fields of Electrical Engineering based on the selected track of study. This project is divided into four major design areas: power system, sensors system, electromechanical systems, and controller/app development. Based on these design areas, the roles were distributed as follows:

- Brian Geibig (EE)
  - Electromechanical Systems
    - Rotation System
    - Shading System
    - Irrigation System
- Abigail Michael (EE)
  - Controller/App Development
  - Controller Design
  - Software Development

- Christina Quinones (EE)
    - Power System
        - Solar Panel and Battery
        - Power Supply
        - Solar Charge Controller
        - Voltage Regulator
- Melissa Rose (EE)
    - Sensors System
        - Light Sensor
        - Temperature Sensor
        - Moisture Sensor
        - WiFi/Bluetooth Module

Even though the design areas were split as described above, all members will contribute their knowledge to any of these areas when a team member needs assistance.

7.6 Future Improvements

When it comes to the mechanical systems, there are many future improvements that could be made. Firstly, optimizing the center compartment that encases the essential electrical components would be one area in which our project could be improved. If the PCB and battery were made to fit more compactly, it would drastically decrease the height of the system as a whole. Also, when it comes to the shading system, the materials used, and the method of deployment could be streamlined in order to make the system lighter and therefore more power efficient. Another physical improvement that could be made within the system would be to install the solar panel on an inclined position, so that it would not have to be lying next to the project on the side and so that it may collect more sunlight. Finally, the cost of many of the physical parts could be decreased by producing them in massive quantities on our own. This would help alleviate the excess expenses of the rotational system, pump, and motors, and make the system cheaper for the target consumer overall.

8.0 Conclusion

The purpose of this project was to create a system that autonomously cared for a plant without the assistance of an outside source. The system would run entirely on its own, allowing the plant to be left alone for long periods of time while still receiving the care that it requires. The design was to be lightweight and easy to use. It should correctly take the data input from the user and turn that into a proper care routine for the plant. The four members of the group agree that this design successfully implemented all of these parameters and will result in a highly effective end product.

Like with any project, challenges arose during the process. The first challenge was coming up with the project itself. Students from senior design in previous years expressed delight in choosing a project as there were multiple sponsored ideas available for them. However, this was not the case this semester. Due to COVID-19, many typical sponsors backed out of their usual deal in order to prevent students from gathering together. This resulted in very few sponsored projects readily available for us to choose from. The four of us spent several weeks getting together and discussing our options. After several brainstorming sessions, this project was decided on.

This project was chosen due to its workload and the tasks required for its completion. Given that this group consists of four electrical engineers and no computer engineers, a project that was more hardware heavy was considered ideal. For this reason, this project was perfect. The systems themselves are geared towards the electrical engineering specialization. Most parts involve the use of hardware from the power system to sensors that run on digital signals. Just about all parts of this project fall directly in the electrical engineering curriculum. Anything not learned in classes could be easily learned with a little research.

Another benefit to the project is the lack of coding. As an electrical engineering student at the University of Central Florida, one is required to take at least one class to learn programming with C – but that is it. The students are not required to study C in great detail nor are they required to learn additional languages. All four members of the group are familiar with the language, but nothing else. This was a deciding factor for the project. Choosing one with little coding would assure that all work could be successfully completed on the knowledge gained in class.

The final deciding factor was the amount of work associated with the project. When initially deciding on the project, numerous stretch goals were considered. These could be easily added or removed from the project to assure that it could be successfully completed in the allotted time period. The alternative ideas were pretty set-in stone with little room to add or take away. For this reason, this design seemed like a perfect fit for our senior design project.

Another challenge was deciding on the final design for the project. Several ideas were thrown out as potential additions to the project to make sure it covered all requirements. They all were excellent ideas that came in all shapes and sizes and would result in a wide variety of final products. After much discussion, it was decided that the final design was to include sensors, a shading system, and a rotational system. The next step was to decide on the look and how these pieces would come together. All members had an idea of what the product would look like, none of which were exactly the same. It was not until the end of the semester that the final design was agreed upon. This design is what can be seen in the schematic shown above. The pot would sit on a base that would allow it to rotate on an axis. The shading system would be a combination of an umbrella and a folding fan and fan out to cover the plant when requested. Finally, the sensors would be placed within the pot, so they receive the most accurate data possible. This was the most efficient design that would best showcase the group's abilities.

The third and final challenge was setting up the budget. At the beginning, the final budget was unclear. Given that very little was known about the final product and the materials required for its completion, it was difficult to successfully determine the amount of money that would be spent on the design. Estimates were made, but they are just that – estimates. There was no way of determining that final amount until all research was conducted and prototyping had begun. It wasn't until after sufficient research had been completed and parts were selected that a better estimate of the budget could be made.

After reviewing the document, the group has collectively agreed that this report holds sufficient information for the design, prototyping, and completion of the project. We believe that all members have conducted enough research to choose the correct parts for their portions of the project and successfully implement them in the final design. This report perfectly encapsulated the purpose of this project and why each decision was made. If an outsider were to read through this report, they would have a full understanding of the design and what to expect when viewing the end product. This report not only covers the choices made for the design but also the budget and the plan for completing it in the allotted time. This report sets the group up for success in Senior Design II.

The next steps in the project involve preparing for Senior Design II. There, the design will be put to test as the actual project will be built and tested. The goal for Senior Design II is to complete the project as quickly as possible so that the group members can all have a successful final semester. Most members will be taking additional classes during the semester and would like to make the workload as easy as possible. This can be achieved by working on the project efficiently so that it can be completed in a timely manner. One step to achieve this goal is ordering parts now. All parts of the system have already been selected. They are all compatible with one another and fit nicely within the budget. There is nothing stopping the group from ordering parts now so the prototyping stage can commence. Therefore, the next step in the process will be to order parts in the near future.

An additional step to help prepare for Senior Design II is to start the prototyping stage now. As stated above, all parts have already been selected and the final design has been determined. There is nothing stopping us from getting a head start on the project. For this reason, the group has agreed to begin the prototyping stage as soon as possible. All members of the group have already agreed to work on the project over the winter break. We have decided on conducting weekly meetings that would allow for status checks and review of the completed work. This will allow for efficient use of time as the group will already be several steps ahead at the start of the new semester. With these additional steps, the plan is to complete the project in a timely manner in order to make the Senior Design II experience as smooth as possible.

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Appendix B - Copyright

Texas Instruments Information and Image Use

CQ **Christina Quinones <christina.quinones1797@outlook.com>**
11/8/2020 10:39 PM

To: copyrightcounsel@list.ti.com

Hello,

I am Christina Quinones, and I am a senior electrical engineering student of the University of Central Florida. I am currently working on a senior design project, and as part of this project I would like to include some of the information and images on your website related to linear and switching voltage controllers. As part of the technical report, I would like to include the information of the different types, as well as the images related to the circuit schematics to make a comparison of all the technology available for voltage regulators. I am writing to request permission to refer to these images and information in the technical report.

Please get back to me at this email, christina.quinones1797@outlook.com or at 787-210-5635.

Thanks in advance,
Christina Quinones

Re: Image Copyrights

JZ **Jack Zalewski <solarteam@energysage.com>**
7:35 PM

To: Christina Quinones

Christina,

Thanks for reaching out to us about this. You are welcome to use our images for your report. Please cite the materials according to the citation guide you are using for your paper.

Best of luck with your design project,

Jack

--
Jack Zalewski
Consumer Support Specialist, EnergySage
| jack@energysage.com

On Sat, Nov 28, 2020 at 4:18 PM EST, Christina Quinones <christina.quinones1797@outlook.com> wrote:

> Hello,
>
> I am Christina Quinones, and I am a senior electrical engineering student of the University of Central Florida. I am currently working on a senior design project, and as part of this project I would like to include some of the information and images on your website related to types of solar panels. As part of the technical report, I would like to include the information of the different types, as well as the images related to the solar panels to make a comparison of all the technology available for solar panels. I am writing to request permission to refer to these images and information in the technical report. The website link is https://www.energysage.com/solar/101/types-solar-panels/.
>
> Please get back to me at this email, christina.quinones1797@outlook.com or at 787-210-5635.
>
> Thanks in advance,
> Christina Quinones

ROHM SEMICONDUCTOR

Americas - English

Products Technical Support

Contact Us

Thank you your interest in ROHM. Please fill in the following information and a representative will contact you to answer your questions and provide the information you requested.

* First Name	Christina
* Last Name	Quinones
* E-mail	christina.quinones1797@outlook.com
* Company	UCF
Department	Electrical Eng.
Tel. Number	7872105635
* Address	4559 Plainview Rd
* Zip/Postal Code	34772
* City	Saint Cloud
* Country	United States For China inquiries, please click here.
* Inquiry Type	Others
* Inquiry	I am Christina Quinones, and I am a senior electrical engineering student of the University of Central Florida. I am currently working on a senior design project, and as part of this project I would like to include
* End-use	☑ I confirm that the content of this inquiry is not for military purposes.

Arduino Image Use Request

Abby Michael <elizabethmichael6@gmail.com> 9:17 AM (0 minutes ago)
to trademark

Good Morning,

My name is Abigail MIchael. I am an electrical engineering student at the University of Central Florida. I am currently working on a senior design project and am requesting permission to use one of your images in my document. The image is the pinout for the ATMega4809 chip which was included in its datasheet.

Please get back to me at elizabethmichael6@gmail.com.

Thank you for your time.

Sincerely,
Abigail MIchael

Dear Abigail,

Thank you for your email. You may include the image in your University project. In addition when you write about Arduino you should add a circled (R) after the word the first time it appears in the text, like this: Arduino®. Also we would like you to add a trademark acknowledgement in the text, it may look like this but can also be modified depending on which trademarks you have used:

ARDUINO® , ARDUINO, and are trademarks of Arduino SA

More information about how to write about Arduino can be found here: https://support.arduino.cc/hc/en-us/sections/360004755719-Community-and-Publications

Good luck with your project and let me know if you have any further questions.

Best Regards,

Sara Therner
Trademark & Licensing Manager

ARDUINO® , ARDUINO, and are trademarks of Arduino SA

Information and Images Usage Permission Request

Christina Quiñones <christina.quinones1797@gm... Thu, Dec 3, 10:20 PM (3 days ago)
to copyrightcounsel

Hello,

My name is Christina Quinones, and I am a senior electrical engineering student from the University of Central Florida located at Orlando, Florida. I am currently working on a senior design project which requires the implementation of voltage regulators. In order to complete the project report, I would like to include some information and images from the datasheets for the linear regulator LM7805 and switching regulator LM2576. I am requesting permission to include this information in the final report. The information and images are coming from the following web addresses:

https://www.ti.com/lit/ds/symlink/lm2576.pdf?ts=1607041735936&ref_url=https%253A%252F%252Fwww.google.com%252F

https://www.ti.com/lit/ds/symlink/lm340.pdf

I would like to include some of this information and images with the proper citations.

Thanks in advance,
Christina Quinones

TI WEBENCH Power Designer

CQ Christina Quinones <christina.quinones1797@outlook.com>
5:10 PM

To: copyrightcounsel@list.ti.com

Hello,

My name is Christina Quinones, and I am a senior electrical engineering student of the University of Central Florida at Orlando, Florida. I am conducting a senior design project that integrates voltage regulation. I would like to have permission to use some of the DC/DC convertors designs generated on WEBENCH Power Designer as reference for the project design.

Please contact me via email at christina.quinones1797@outlook.com or via phone at 787-210-5635.

Thanks in advance,
Christina Quinones

Contact Us

Contact the Electronics Tutorials Team

We always encourage you to share your ideas and improvements with us, so if you have any questions about our Electronics Tutorials website, please feel free to contact us using the form below. Many thanks for your show of support.

Message Sent (go back)

Email: melissarose702@gmail.com

Message: Hi Electronics Tutorials Team,

I am a electrical engineering student at the University of Central Florida working on my Senior Design project. Could I please have the permission to use the following figures?

Light Presence versus Resistance for an LDR figure - "Light Sensors" - https://www.electronics-tutorials.ws/io/io_4.html

Light Presence versus Resistance for an LDR figure - "Light Sensors" - https://www.electronics-tutorials.ws/io/io_4.html

Operation and IV Curve of the Photodiode in Reverse Bias Mode. - "Light Sensors" - https://www.electronics-tutorials.ws/io/io_4.html

Operation and IV Curve of the Phototransistor. - "Light Sensors" - https://www.electronics-tutorials.ws/io/io_4.html

Thermocouple Operation. - "Temperature Sensors" - https://www.electronics-tutorials.ws/io/io_3.html

Please email me at melissarose702@gmail.com.

Thank you!
Melissa Rose

Permissions

Melissa Rose <melissarose702@gmail.com>
to support

9:48 PM (0 minutes ago)

Hi,

I am an electrical engineering student working on a senior design project. I am using the Easy EDA editor for PCB design. Could I please include schematic and board images created in the software in my documentation? I can be reached back at melissarose702@gmail.com.

Thanks!
Melissa Rose

Reply | Forward

Permissions

Melissa Rose <melissarose702@gmail.com>
to MHE-Permissions

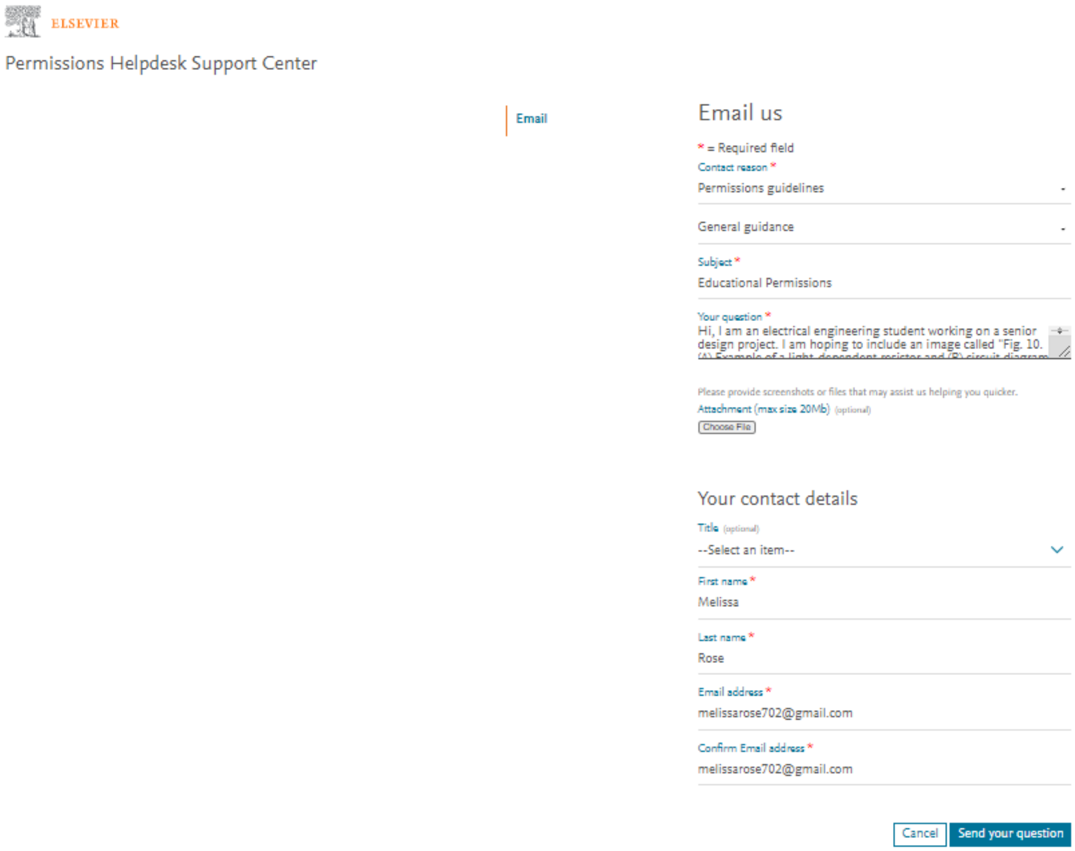
10:13 PM (0 minutes ago)

Hi MH Education,

I am an electrical engineering student working on a senior design project. I am hoping to include an image called "FIGURE 6.6 Using a thermistor as a thermometer" from *Practical Electronics for Inventors* (ISBN: 9781259587542). Could I please use this image in my documentation? I can be reached back at melissarose702@gmail.com.

Thanks!
Melissa Rose

Reply | Forward


ELSEVIER

Permissions Helpdesk Support Center

Email

Email us

* = Required field

Contact reason *

Permissions guidelines

General guidance

Subject *

Educational Permissions

Your question *

Hi, I am an electrical engineering student working on a senior design project. I am hoping to include an image called "Fig. 10.

Please provide screenshots or files that may assist us helping you quicker.

Attachment (max size 20Mb) (optional)

Choose File

Your contact details

Title (optional)

--Select an item--

First name *

Melissa

Last name *

Rose

Email address *

melissarose702@gmail.com

Confirm Email address *

melissarose702@gmail.com

Cancel Send your question

Appendix C - Datasheets

1. Advanced Photonix, “Photocell”, https://cdn-learn.adafruit.com/assets /assets/000/010/127/original/PDV-P8001.pdf
2. Everlight, “Ambient Light Sensor Surface - Mount ALS-PT19-315C/L177/TR8”, https://cdn-shop.adafruit.com/product-files/2748/2748+datasheet.pdf
3. Microchip Technology Inc. *ATmega809/1609/3209/4809 – 48-Pin*. Microchip Technology Inc, 2019, https://content.arduino.cc/assets/Nano-Every_processor-48-pin-Data-Sheet-megaAVR-0-series-DS40002016B.pdf
4. *MSP430FR698x(1), MSP430FR598x(1) Mixed-Signal Microcontrollers*. Texas Instruments, www.ti.com/lit/ds/symlink/msp430fr6989.pdf?ts=1606089193714&ref_url=https%253A%252F%252Fwww.ti.com%252Fproduct%252FMSP430FR6989%253FkeyMatch%253DMSP430FR6989%2526tisearch%253DSearch-EN-everything%2526usecase%253DGPN.
5. Sensor Solutions, “Photocell” https://cdn-learn.adafruit.com /assets/assets/000/010/128/original/DTS_A9950_A7060_B9060.pdf
6. SparkFun Electronics , “ESP8266 Module.” https://cdn.sparkfun.com/assets/ f/e/5/6/f/ESP8266ModuleV2.pdf
7. TE Connectivity, “Negative Coefficient Chip Thermistors.” https://www.te.com/commerce/DocumentDelivery/DDEController?Action=srchrtrv&DocNm=1773258&DocType=DS&DocLang=English
8. Texas Instruments “LM2576xx Series SIMPLE SWITCHER® 3-A Step-Down Voltage Regulator,” SNVS107E datasheet, June 1999 [Revised June 2020] https://www.ti.com/lit/ds/symlink/lm2576.pdf?ts=1605115415484&ref_url=https%253A%252F%252Fwww.startpage.com%252F
9. Texas Instruments “LM2596 SIMPLE SWITCHER® Power Converter 150-kHz 3-A Step-Down Voltage Regulator,” SNVS124E datasheet, Nov. 1999 [Revised Feb. 2020] https://www.ti.com/lit/ds/symlink/lm2596.pdf?ts=1605118629063&ref_url=https%253A%252F%252Fwww.google.com%252F
10. Texas Instruments, “LM2575 1-A Simple Step-Down Switching Voltage Regulator,” SLVS569F datasheet, Jan. 2005 [Revised Aug. 2015] https://www.ti.com/document-viewer/LM2575/datasheet
11. Texas Instruments, “LM317 3-Terminal Adjustable Regulator,” SLVS044Y datasheet, Sep. 1997 [Revised Apr. 2020] https://www.ti.com/lit/ds/symlink/lm317.pdf?ts=1604945375373&ref_url=https%253A%252F%252Fwww.google.com%252F
12. Texas Instruments, “LM340, LM340A and LM7805 Family Wide VIN 1.5-A Fixed Voltage Regulators,” SNOSBT0L datasheet, Feb. 2000 [Revised Sept. 2016] https://www.ti.com/lit/ds/symlink/lm340.pdf?ts=1605110214938&ref_url=https%253A%252F%252Fwww.google.com%252F
13. Vishay, “VELM6030.” https://www.te.com/commerce/DocumentDelivery/ DDEController?Action=srchrtrv&DocNm=1773258&DocType=DS&DocLang= English

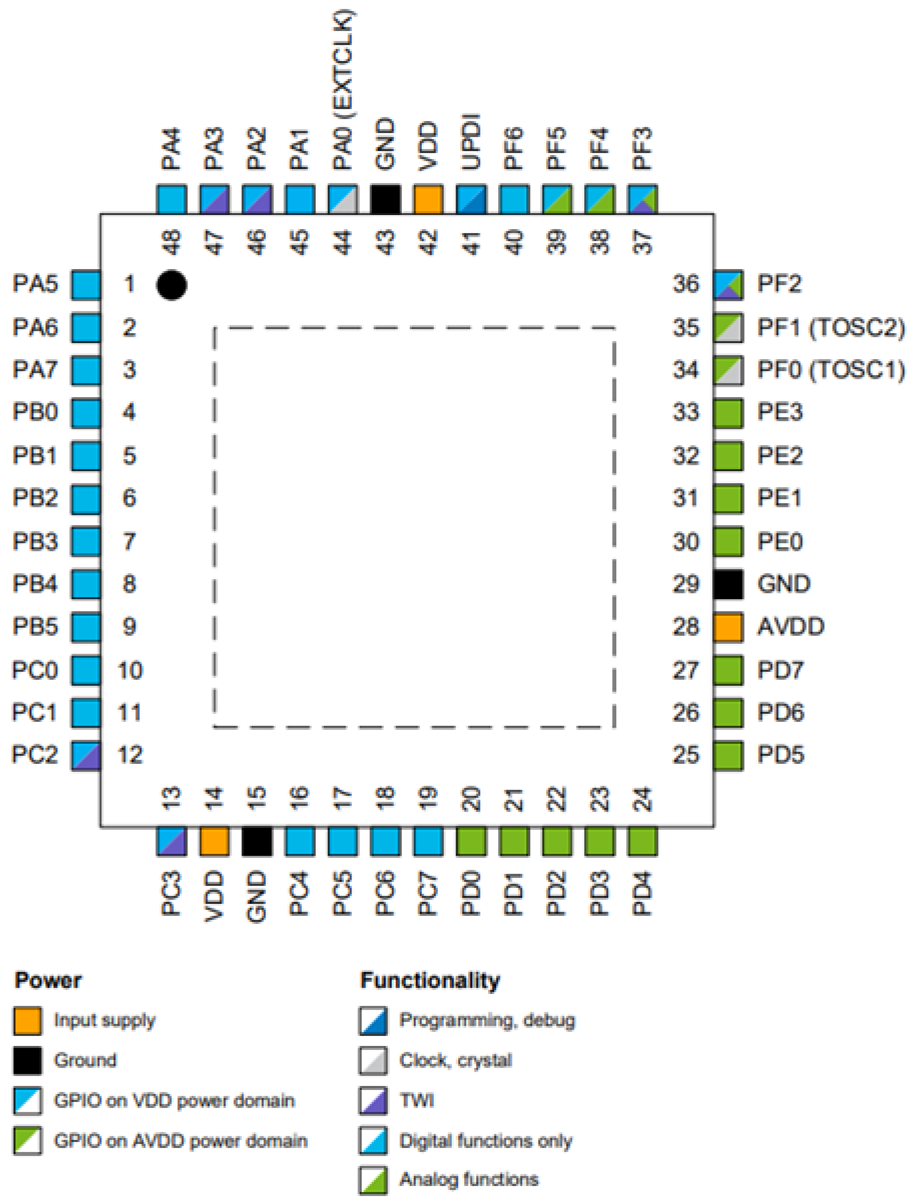


Figure 77: Pinout Diagram of ATMega4809 (Microchip, 6) (Reprinted with Permission of Arduino)

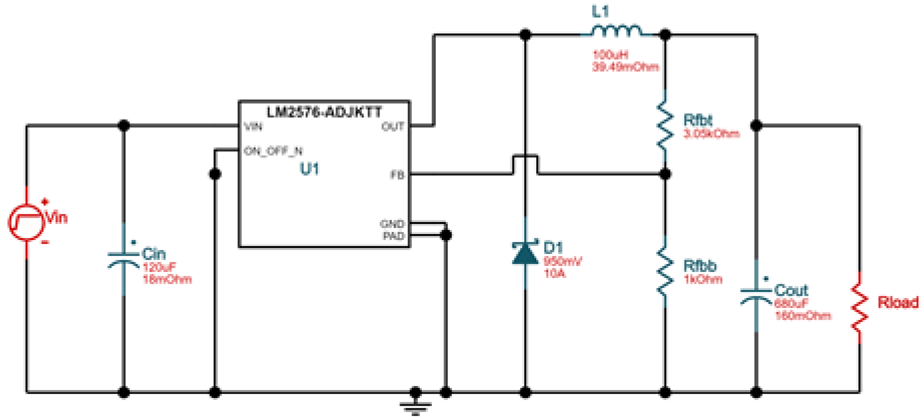


Figure 78: 5V Switching Voltage Regulator *(WEBENCH)*

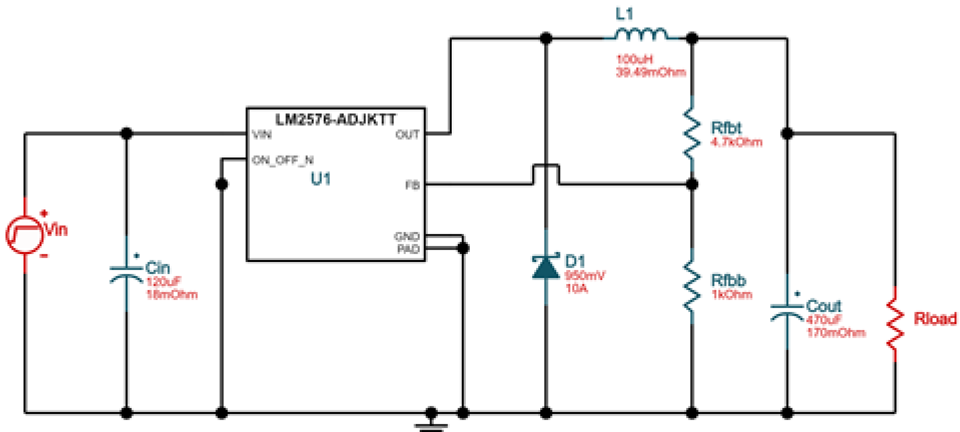


Figure 79: 7V Switching Voltage Regulator *(WEBENCH)*

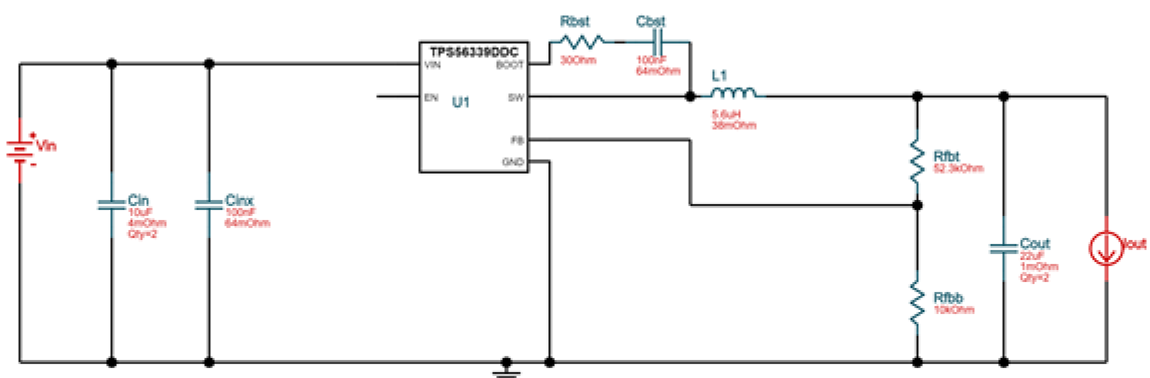


Figure 80: 5V Switching Voltage Regulator using TPS56339DDC *(WEBENCH)*

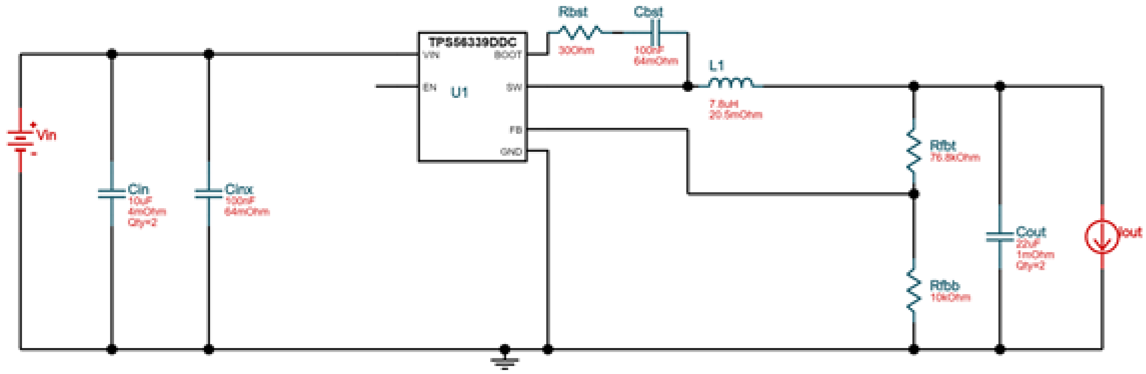


Figure 81: 7V Switching Voltage Regulator using TPS56339DDC *(WEBENCH)*