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SENIOR DESIGN I

Initial Project and Group Identification Document

60 Page Document

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

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Table of Contents

List of Figures

List of Tables

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 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. There will be multiple systems within this device that will assure that the plant receives all that it needs in a timely manner.

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 once again receive sunlight. 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. This provides an exceptional solution to the problem at hand.

2.0 Project Description

2.1 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.

2.2 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 in order 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. In order 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.

2.3 Engineering Requirements Specifications

Section	**Requirements**
Power System	Must be capable of powering multiple sensors, a controller, and multiple mechanical systems Must output a minimum power of 20 W Must have current leakage protection The battery connected to the solar panel must have a capacity of 5Ah or greater.
Solar Charge Regulator	Must have overcharge protection to limit current when fully charged battery Its output voltage shall be within the range of 12.6V to 13.7V while the solar panel is receiving energy (light)
Irrigation System	Automatically turns on once moisture level falls below application set value and turns off once level is acceptable again. Must be able to pump water at a rate greater than 0.2 Liters/Minute.
Light Sensor	Must detect a minimum of 10000 lux Must communicate to the microcontroller's ADC input
Moisture Sensor	Must be able to calibrate a certain plant's soil moisture output to fit a range of 1024 bits Must be resistant to corrosion due to moisture
Shading System	Must be able to take an input from the application, and electrically open and close to shade the plant.
WiFi Module	Must successfully connect to the Internet following the 802.11 protocol and WPA2 security settings
Microcontroller	Must successfully communicate with the other components via UART/SPI and consume no more than 50mA and operate at a voltage no more than 5V
Application	Must be installable within 5 minutes with a file size under 20 MB and be able to successfully send inputs to the microcontroller via WiFi.

Table 1: List of Requirement Specifications

2.4 Marketing and Engineering Requirements

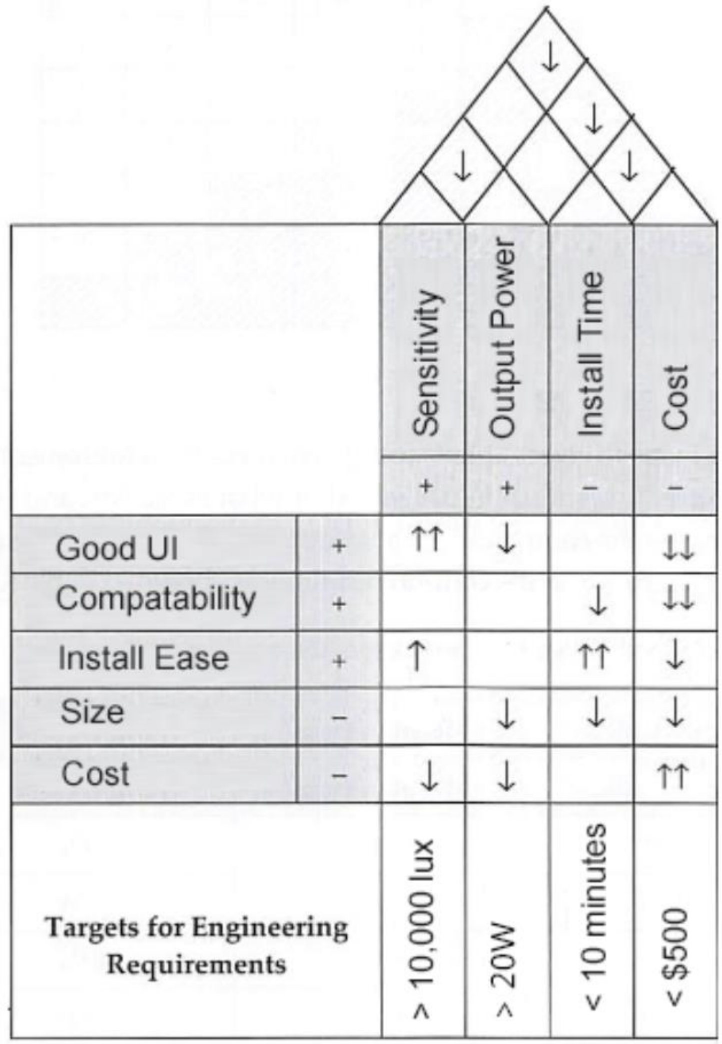

Figure 1: House of Quality Diagram

2.5 Block Diagram

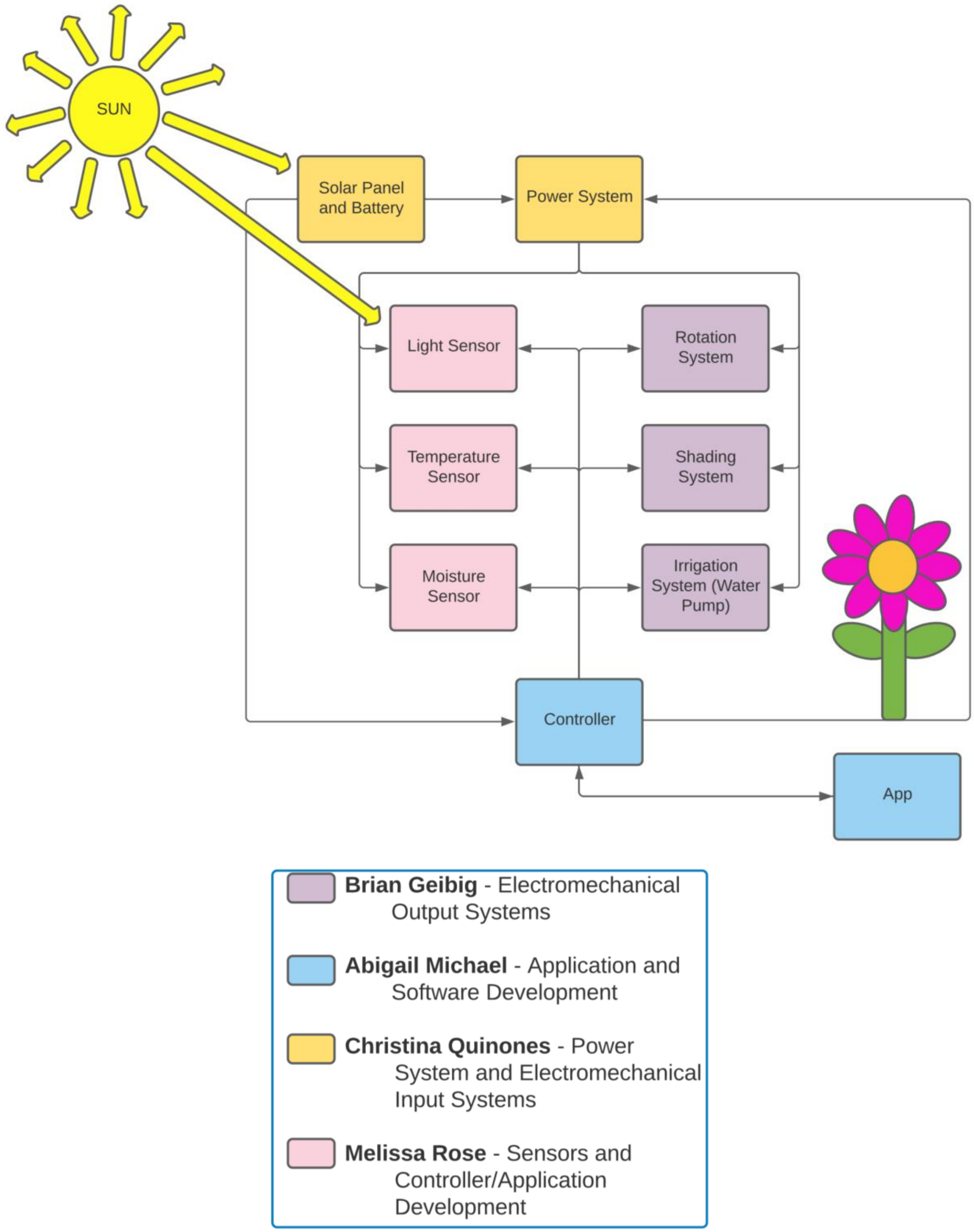

Figure 2: Project Block Diagram

3.0 Research

3.1 Existing Projects and Products

3.1.1 Plant Pot with Sensor

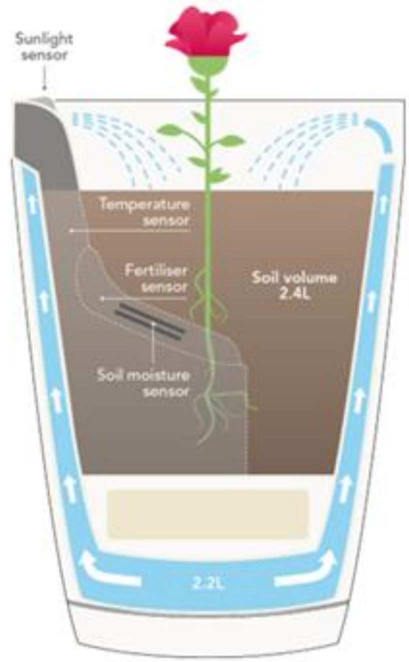

Figure 3: Existing Plant Pot with Sensors and Automatic Watering System *(Parrot Pot)*

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.

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.

3.1.2 Plant Pot with Rotation System

Figure 4: Existing Manual Rotating System *(GeBot Rolling Steel Potted Plant Stand)*

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 5: Existing Electric Motorized Rotating Turntable Stand *(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.

3.1.3 Plant Pot with Shading System

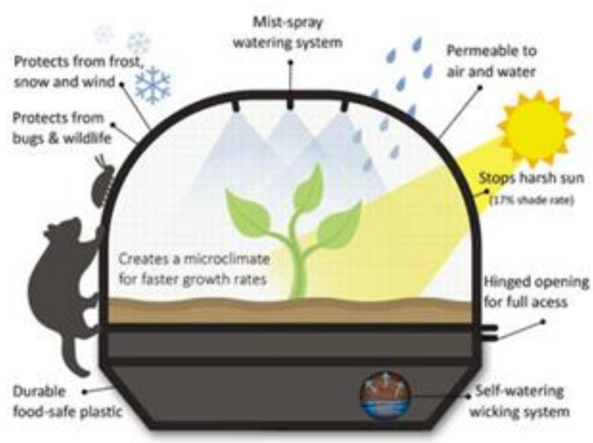

Figure 6: Existing Shading Systems for Plant Pots *(Vegepod)*

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.

3.2 Relevant Technologies

3.2.1 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.

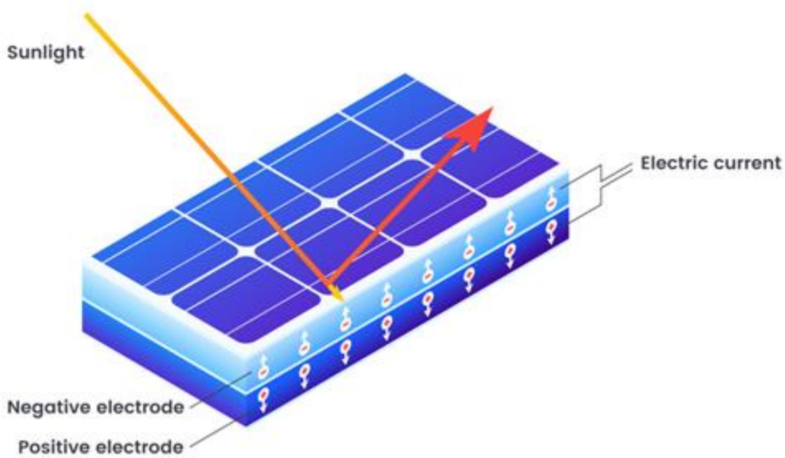

Figure 7: Photovoltaic Cell

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.

3.2.2 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.

There are two major types of voltage regulators: linear regulators and switching regulators.

3.2.2.1 Linear Voltage Regulator

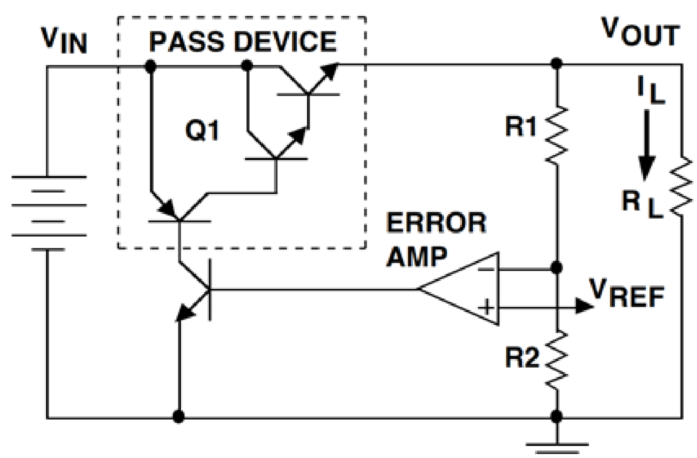

Figure 8: General Linear Voltage Regulator Schematic *(Texas Instruments)*

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.

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.

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

3.2.2.1.1 Standard (NPN Darlington) Regulator

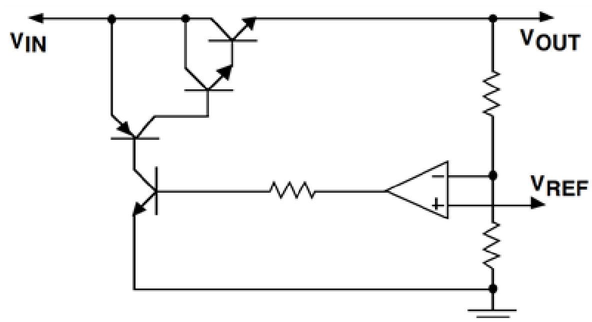

Figure 9: Standard (NPN Darlington) Regulator *(Texas Instruments)*

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:

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

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.

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.

3.2.2.1.2 Low Dropout or LDO Regulator

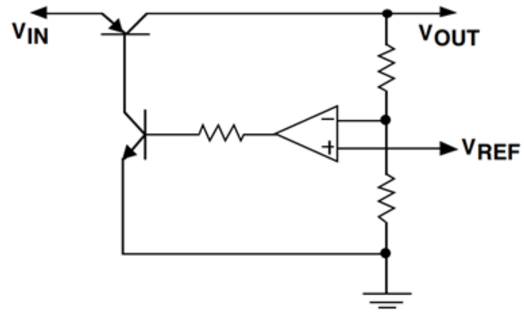

Figure 10: Low Dropout (LDO) Regulator *(Texas Instruments)*

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:

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

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.

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.

3.2.2.1.3 Quasi LDO Regulator

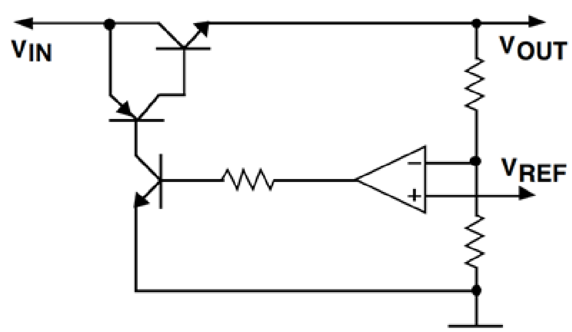

Figure 11: Quasi Low-Dropout Regulator *(Texas Instruments)*

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:

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

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°C. On the other hand, the ground pin current is very low as that of the Standard regulator.

3.2.2.2 Switching Voltage Regulator

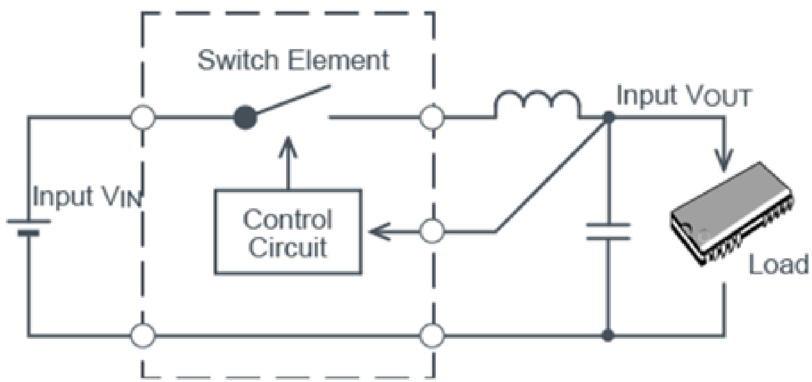

Figure 12: General Switching Voltage Regulator Schematic *(Rohm Semiconductor)*

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.

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.

3.2.2.2.1 Buck Regulator

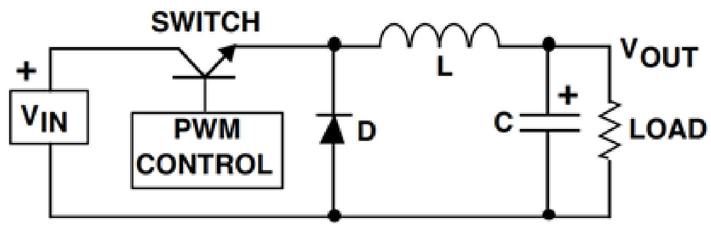

Figure 13: Buck Regulator *(Texas Instruments)*

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.

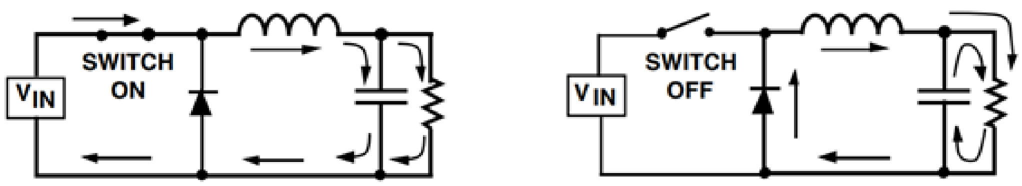

Figure 14: Buck Regulator Switching Current Flow Paths *(Texas Instruments)*

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.

3.2.2.2.2 Boost Regulator

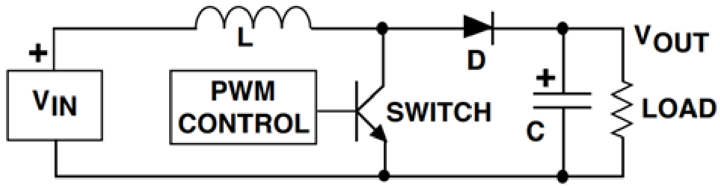

Figure 15: Boost Regulator *(Texas Instruments)*

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.

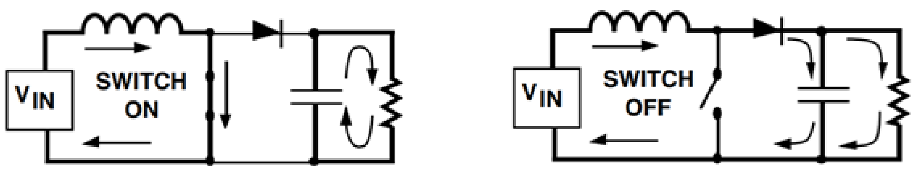

Figure 16: Boost Regulator Switching Current Flow Paths *(Texas Instruments)*

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.

3.2.3 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.

3.2.4 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.

3.2.4.1 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.

3.2.4.2 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.

3.2.4.3 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 two to three times bigger. Also, the energy density of these batteries approaches that of lithium-ion batteries.

3.2.4.4 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.

3.2.4.5 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.

3.2.4.6 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 of time.

3.2.5 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.

3.2.5.1 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).

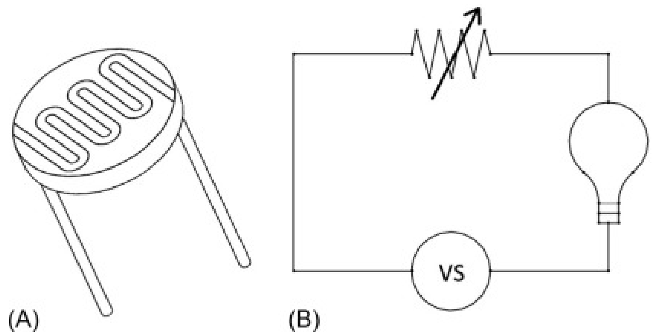

Figure 17: (A) Photoresistor. (B) Basic Bulb Circuit where photoresistor is represented as a variable resistor. (Haraoubia, Non-Linear Electronics 1)

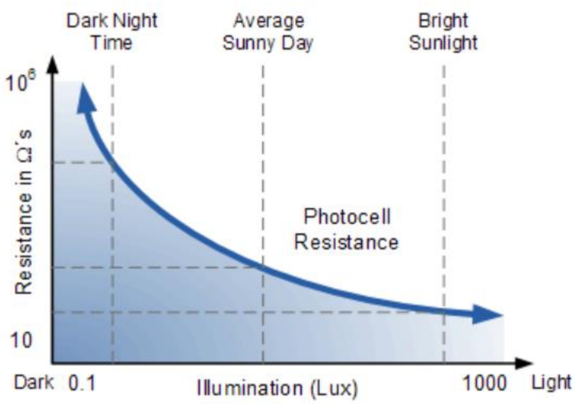

Figure 18: Light Presence versus Resistance for an LDR. (Electronics Tutorials)

3.2.5.2 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).

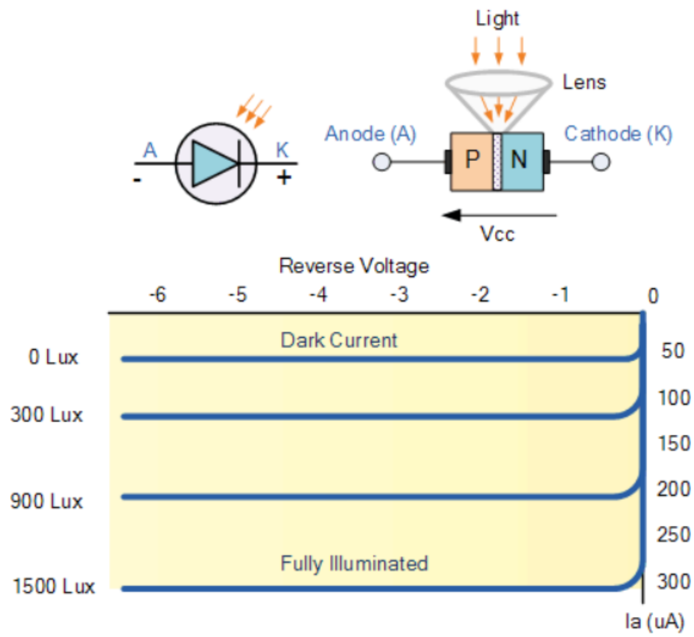

Figure 19: Operation and IV Curve of the Photodiode in Reverse Bias Mode. Source: Electronics Tutorials

3.2.5.3 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). Photothyristors or silicon controlled rectifiers (SCRs), optoisolators, and fibre 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).

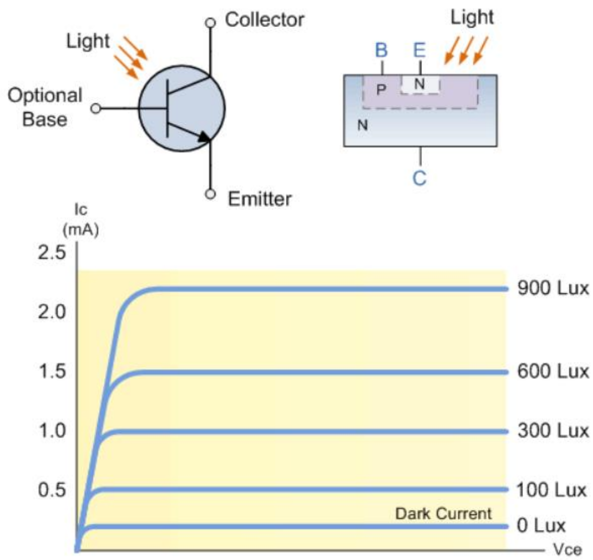

Figure 20: Operation and IV Curve of the Phototransistor. Source: Electronics Tutorials

3.2.6 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.

3.2.6.1 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).

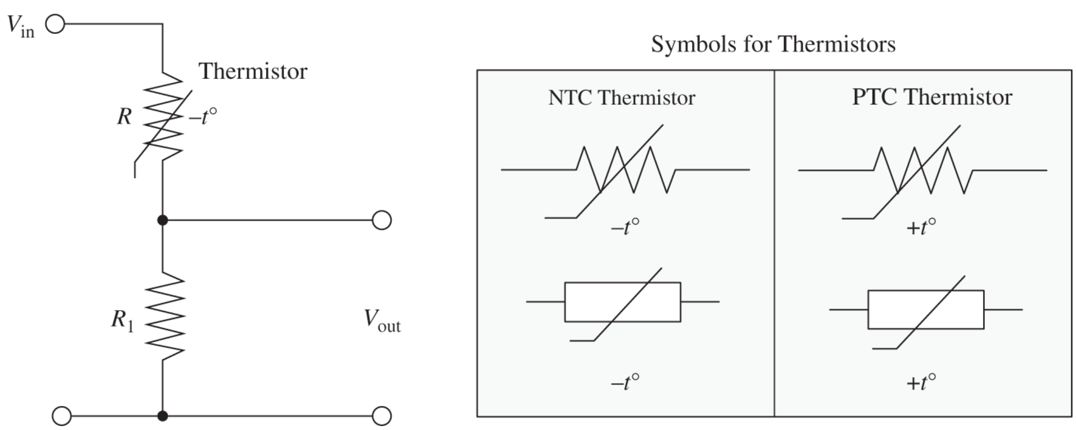

Figure 21: PTC and NTC Thermistors and Its Voltage Divider Network. Source: Scherz, *Practical Electronics for Inventors*

3.2.6.2 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°C 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).

3.2.6.3 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 particular 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).

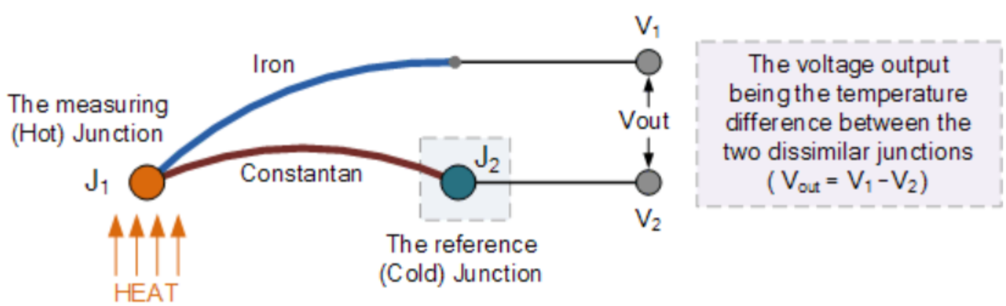

Figure 22: Thermocouple Operation. Source: Electronic Tutorials

3.2.6.4 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).

3.2.7 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.

3.2.8 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.

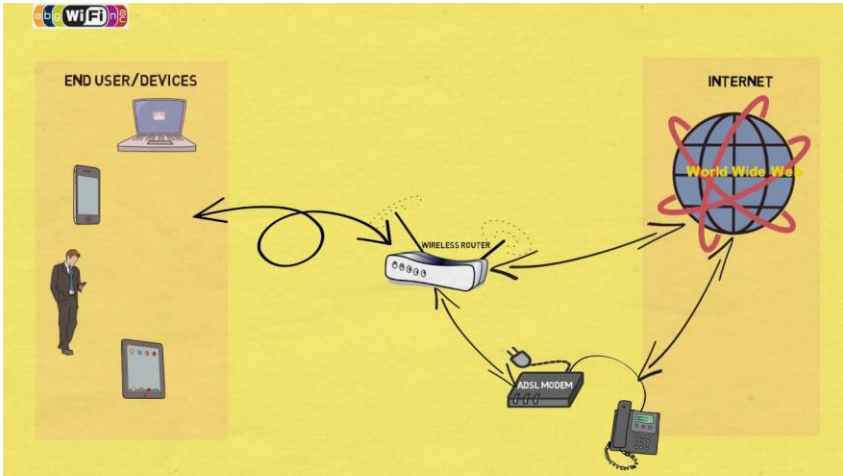

Figure 23: WiFi Process. Source: curiousparti (YouTube)

3.2.9 Microcontroller

A microcontroller is an embedded system with a CPU, memory, and various input and output ports. It has the ability to 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.

3.2.10 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.

3.2.11 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.

3.3 Part Selection

3.3.1 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.

3.3.1.1 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 (ESO8266) 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.

3.3.1.2 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.

3.3.1.2.1 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.

3.3.1.2.2 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.

3.3.1.2.3 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.

3.3.1.2.4 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.

3.3.1.2.5 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.

3.3.1.2.6 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.

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 battery for the entire design will be selected.

3.3.1.3 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.

3.3.1.4 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.

3.3.1.5 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.

3.3.1.6 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.

3.3.1.6.1 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
Max. Output Current	1.5A	1.5A	1.5A
Output Voltage (typical)	5V	5V	1.25V – 37V
Output Options	Fixed	Fixed	Adjustable
Operating Temp	0°C to 125°C	0°C to 125°C	0°C to 125°C
Efficiency	Varies (~50%)	Varies (~50%)	Varies (~50%)
Switching Frequency	N/A	N/A	N/A
Unit Price	$0.90	$1.54	$1.69

Table 3: 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.

3.3.1.6.2 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
Output Voltage (typical)	Varies (Fixable to 5V)	Varies (Fixable to 5V)	Varies (Fixable to 5V)
Output Options	Adjustable	Adjustable	Adjustable
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 4: Switching Voltage Regulators Comparison Table

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.

3.3.1.6.3 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.

3.3.2 Sensors

3.3.2.1 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.

3.3.2.1.1 Photoresistors (LDRs)

Photoresistors, or photocells, are essentially light-controlled variable resistors. Based on the guide from Adafruit and Mouser, they have the following specifications: resistance range from 200k ohms in the dark to 10 km ohms in brightness at 10 lux. 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 (Adafruit). There'll be two photocells equally spaced out on the outside of the plant pot. Each cell would be in a voltage divider, 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.

3.3.2.1.2 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, which is a diode turned on by light. 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.

3.3.2.1.3 Final Decision

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.

3.3.2.2 Temperature Sensor

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

3.3.2.2.1 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.

3.3.2.2.2 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. It's 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

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.

3.3.2.3 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.

3.3.2.4 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 (ESP8266 datasheet). Its well-supported documentation and good price make it a good fit for this project.

3.3.3 Mechanical Outputs

3.3.3.1 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.

3.3.3.2 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.

3.3.3.3 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.

3.3.4 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.

3.3.4.1 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)

3.3.4.2 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.

3.3.4.3 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.

3.3.4.4 Arduino Nano 33 BLE

The last 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 of 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)*

3.3.4.5 Final Decision

All four 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
Chip	ATmega328	ATMega4809	SAMD21 Cortex®-M0+ 32bit low power ARM MCU	nRF52840
Voltage	5 V	5 V	3.3 V	3.3 V
Power Consumption	19 mA	20 mA	7 mA	15 mA
I/O Ports	22 (6 PCM)	20	14	14
Clock Rate	16 MHz	20 MHz	48 MHz	64 MHz
Flash Memory	32 KB (2 KB bootloader)	48 KB	256 KB	1 MB
SRAM	2KB	6 KB	32 KB	256 KB
EEPROM	1 KB	256 B	None	None
Wi-Fi Module	No	No	Yes	Yes
Cost	$20.70	$10.90	$18.40	$20.20

Table 5: Comparison of Development Boards

For this project, four development boards were considered – Arduino Nano, Arduino Nano Every, Arduino Nano 33 IOT, and Arduino Nano 33 BLE. 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). Both the Arduino Nano 33 IOT and the Arduino Nano 33 BLE 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)*

3.3.5 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.

3.3.5.1 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)*

3.3.5.2 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.

3.3.5.3 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)*

3.3.5.4 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.

3.3.5.5 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)*

It is also important to note that I2C was not included in the datasheet and therefore, cannot be used as a form or communication with this chip. Although I2C is a useful method for communication among components of a microcontroller, it is not vital to its success and can easily be replaced by a counterpart. Therefore, the lack of ability will not hinder this project. *(Microchip, 31)*

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, USART will be used for this project. For one, USART can be implemented with a clock. 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 use of acknowledgements. For this project, messages must be sent and received in order for the project to be deemed a success. If the irrigation system misses the signal to stop watering, it will continue to water for an extended period of time. This can be incredibly problematic as the plant will become flooded with too much water. Using an acknowledgment will assure that all components receive the messages that they require. *(Microchip, 31)*

3.3.6 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.

3.3.6.1 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. *(Power Apps 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.

3.3.6.2 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.

3.3.6.3 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 of 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 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. The 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 using 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 cases 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 would 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*)

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.

3.3.6.4 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 insert 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 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*)

3.4 Possible Designs and Related Diagrams

4.0 Design Constraints and Standards

4.1 Realistic Design Constraints

4.2 Related Standard

5.0 Design

6.0 Integration and Testing

7.0 Administrative Content

7.1 Milestones

7.1.1 Senior Design I Milestones

Senior Design I		
Activity	**Date**	**Status**
I. Ideas	-	Completed
II. Project Selection and Role Assignment	-	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	In Progress
5. Final Documentation	12/8/2020	In Progress
IV. Research, Documentation and Design		
1. Light Sensor	12/8/2020	Designing
2. Temperature Sensor	12/8/2020	Designing
3. Moisture Sensor	12/8/2020	Designing
4. WiFi/Bluetooth Module	12/8/2020	Designing
5. Solar Panel	12/8/2020	Designing
6. Power Supply System	12/8/2020	Designing
7. Rotation System	12/8/2020	Designing
8. Shading System	12/8/2020	Designing
9. Irrigation System	12/8/2020	Designing
10. Microcontroller	12/8/2020	Designing
11. PCB Layout	12/8/2020	Designing
12. App	12/8/2020	Designing

Table 6: Senior Design I Project Milestones

7.1.2 Senior Design II Milestones

Senior Design II		
Activity	**Date**	**Status**
1. Build Prototype	4 weeks	-
2. Testing and Redesign	2 weeks	-
3. Finalize Prototype	2 weeks	-
4. Peer Presentation	TBA	-
5. Final Report	TBA	-
6. Final Presentation	TBA	-

Table 7: Senior Design II Project Milestones

7.2 Budget

Section	**Cost**
Plant System	$10
Irrigation System	$40
Light Sensor	$5
Moisture Sensor	$5
Temperature Sensor	$10
WiFi/Bluetooth Module	$10
Rotation System	$30
Shading System	$50
Microcontroller Kit	$80
Power System (including Battery)	$50
Solar Panel	$30
Software Development	$0
Total	$320

Table 8: Project Cost Breakdown

The cost breakdown is based on suppliers given in the Sources section. 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 because of university subscription.

The total cost is estimated to be $320, more $1680 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.

7.3 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.

7.4 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.

7.5 Future Improvements

8.0 Conclusion

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Appendix B - Copyright

Appendix C - Datasheets

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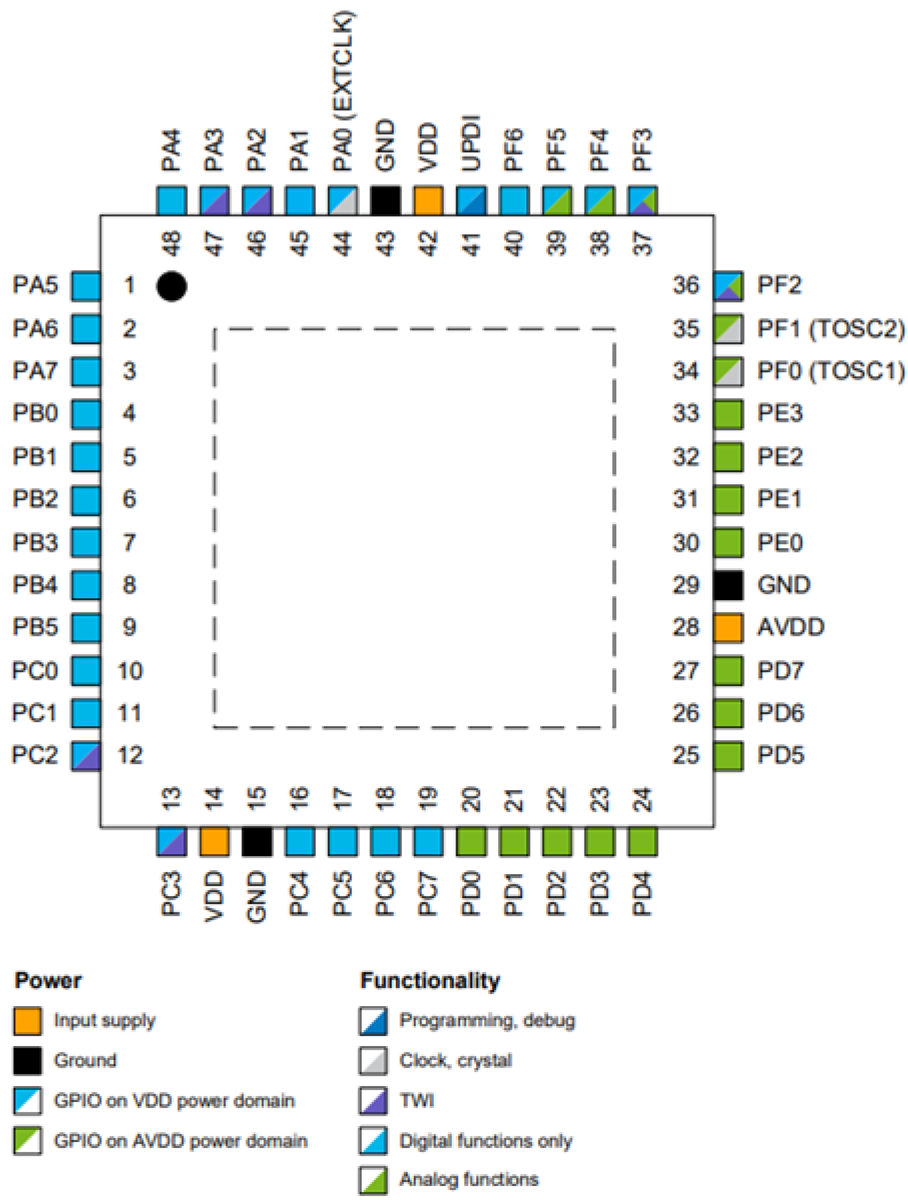

Figure 24: Pinout Diagram of ATMega4809 (Microchip, 6)