Plant Nanny

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1. Executive Summary

Not everyone is born with a green thumb, but every plant has needs. The basics being water, soil, and sunlight. However, these aren't the only factors that play into a plant's life span and health. No plant can grow in any temperature or humidity, and people can have trouble satisfying a plant's needs through normal outdoor conditions. The Plant Nanny is the solution.

The Plant Nanny is essentially a personal plant whisperer with additional perks. It tells the user everything about their plants, lets them control their plant's environment, and even waters their plant. All these features are integrated into one indoor system that not only meets all the plant's basic needs, but also helps to perfect their environment. Through this self-sufficient system, almost any small plant can thrive under ideal conditions that never waiver.

The average person has a hefty amount of responsibility, and sometimes your mind will block out tasks that aren't as important. For example, a proposal is due in three days and you're the one in charge. You work all night and day to finish this proposal for three days and finally it's complete. However, when you return home your plant is already wilting and in desperate need of attention. This is where The Plant Nanny shines by taking care of this other responsibility. It tracks the plant's environmental conditions and displays an ideal range of where a certain variable should be.

The way that someone sets up The Plant Nanny is simple. The user should simply take a pot filled with soil and either a plant or seed, and they place it into one of the open spots under a UV lamp. The only other requirement is to place the included sensors either in the soil of the pot or around that general area to get accurate readings. At this point the data should start to register values, and you're able to access all this information from an app. This will help keep tabs on the health of your plant even from across the world. With a built-in water reservoir, the plant can be automatically watered without having to lift a finger. The Plant Nanny will combat any problem with its indoor growing solution.

2. Project Description

The supply of a self-sufficient plant care device provides the opportunity for more independence when taking extended leave from your plant. The goal is to avoid as much dependence a plant can have on a person to give that plant a greater chance of survival by taking out the middle variable. This will all require almost no effort on the plant owner's part and will improve the overall living conditions of any given plant they decide to grow. The process should be as easy as setting a up some environment variables through a phone app, and then the plant should be self-sustaining.

The following section will cover:

- What motivation we had to go through the design process of creating this project.
- How we planned out to accomplish the entire scope of this project.
- Some of the specifications and requirements on how this project came into fruition.
- The house of quality chart for the different parts of this project.

2.1 Project Motivation

Everyone wants fresh vegetables when they enter a grocery store, and no one wants a decaying plant to go in their latest food creation. The ingredients that go into your dish should always be fully green and full to the brim with nutritious content. Whether it's some basil you're carefully tearing apart and putting into a vibrant risotto or tomatoes that you're mashing up and using for a tomato sauce, these ingredients deserve to be in full bloom for someone that comes home from work. This leads to the problem of when there are so many things to take care of in your daily life, how are you supposed to remember to water a plant outside. It's out of the way probably in a place that it is untouched and could be easily forgotten, and you must constantly water it every day.

This was where a busy engineering student decided enough was enough, and they wanted to take matters into their own hands. They had left their herb plants unattended for a week or so after a plethora of late-night assignments, and once they had finally checked up on their plant only to find it withered and without life. Due to constraints and lifestyle, it can be hard to remember and find the time to water and nurture a plant. This is where they decided to solve the problem through a design project. They had always wanted to make something practical for not just themselves, but also society. The need for a system that was smart enough to take care of itself as well as the plants became a necessity. This was the project that would decide exactly what a plant wanted, and how to satisfy all the environment variables.

It's difficult to remember a plant outside when you come home and all you want to do is relax on the couch. That's why an indoor plant system became important for the final revision of this project. The ability to see the plant and remember to take care of it, by refilling the water reservoir or whatever duty the plant may require, was an important aspect of choosing this constraint. Another important aspect was for the system to be a complete encompassing of all the environment variables that could affect a plant. This required to look out for more than just the water content in the soil. The system must look out for all these variables in an indoor environment, and this is the last constraint towards creating a project to fulfill anyone's desires for fresh produce.

With the project complete, anyone should be able to grow almost any plant with ease, and this all comes together towards helping the consumer with their own personal lifestyle. It's meant to allow the person to live their lives without having to constantly fret about a plant outside that they need to take care of to create their latest kitchen dish. The challenge of keeping a plant alive should be nonexistent after the extent of this project.

2.2 Project Goals & Objectives

To create an indoor ecosystem for people who can't take responsibility every day for some type of produce requiring daily care. The plan is to create a self-sufficient gardening system that's capable of taking care of multiple plants. This will be done through a UV lamp placed over the top of three potted plants and have an automated watering system. There would be a water reservoir that would constantly water the plants when their soil runs too dry. The temperature would be measured to help the user find an optimal place to place the system to keep the plants at an acceptable temperature.

All these features would come together into a single device that keeps a plant alive and thriving. Although this system might seem sophisticated at first, a main objective is to keep this system simple for the user and the plant. Although it's a complex system, the design and simple objective remain. This is an all-encompassing self-sufficient plant system that will take care of a plant when there might be multiple days of neglect before any care is given.
It's meant to give produce that is not only alive, but hopefully thriving and full of life to add to a person's diet. The end goal of this isn't just to create a system that keeps a plant alive, it's to help a person with their daily life chores and hopefully reduce their load of daily work.

2.3 Requirements

The reason for creating the project requirements and specifications section is to have a guide when developing and implementing the Plant Nanny design. An outline to ensure that we stay on track when developing the system. It will describe in detail all the functionality the system shall perform. This section will assist with the testing, developing, and designing of the Plant Nanny. To help us achieve the primary goal of creating a system that will help the user keep their plants alive and ensuring the plants will grow. See the table below (Table 2.1) for our list of requirements for this design project.

Table 2. 1– List of Requirements

Identifier	Requirement	Values
SCS-1	System shall have the ability to properly water the plant after initial calibration of soil moisture levels using soil moisture sensors	Half liter of water per plant
SCS-2	System shall have the ability to communicate over a 2.4Ghz Wi-Fi connection	2.4GHz
SCS-3	System shall have the ability to recognize and turn off when the plant consumed enough UV light	6 hours of UV light
SCS-4	System shall have a Cost of Production less than $400	$400
SCS-5	System shall be able to be controlled by the app.	100% of the time
SCS-6	System shall measure soil moisture on a scale from 0 at driest to 880 at most saturated with an initial calibration	Scale from 0-880
SCS-7	System shall have the ability to measure water flow from 0 to 1.5 liters per minute	0 to 1.5L per minute
SCS-8	System shall be able to detect when the level is below 100, 75, 50 25 and 10`1	100%, 75%, 50%, 25%, 10%
SCS-9	System shall have no components consuming voltages greater than 12V	12V
SCS-10	System shall run without an issue for 1hr when testing	1 hour
SCS-11	The output of the transformer voltage should output 12-14 volts	12 to 14 Volts
SCS-12	With a full sun the solar panel shall provide 110mA of current	110mA
SCS-13	The Plant Nanny shall weight less than 10lbs	Less than 10lbs
SCS-14	The Plant Nanny dimension shall not be bigger than 10X36X36in	10x36x36in
SCS-15	The water reservoir shall not be larger than 2 gallons	Water reservoir less than 2 gallons

2.4 House of Quality Analysis

The House of Quality (HOQ) is defined as a product planning matrix that built to show the customer requirements relate directly to the ways and methods companies can use to achieve those requirements [1]. It is represented as a diagram that takes the shape of a house, hence the name 'house of quality'. The house of quality is an excellent tool that is typically used in the beginning stages of project design to implement a properly functioning product and help facilitate decision making. You will see the Plant Nanny House of Quality diagram pictured below (Figure 2.1).

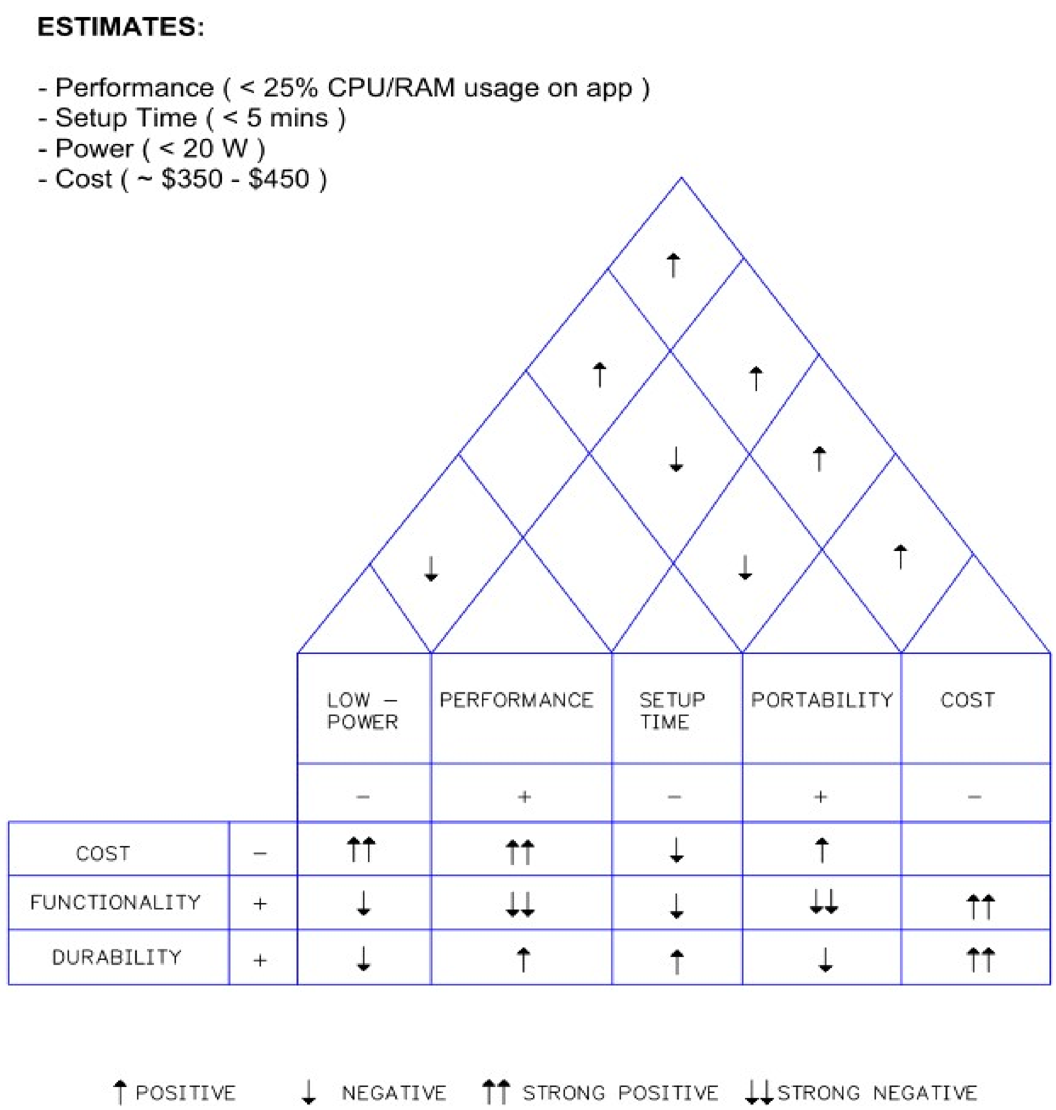


Figure 2. 1: House of Quality Analysis

2.5 Project Block Diagram

The figure pictured below (Figure 2.2) is an overview and estimation of how our project PCB and various components will interact and be connected to function as one whole complete unit.

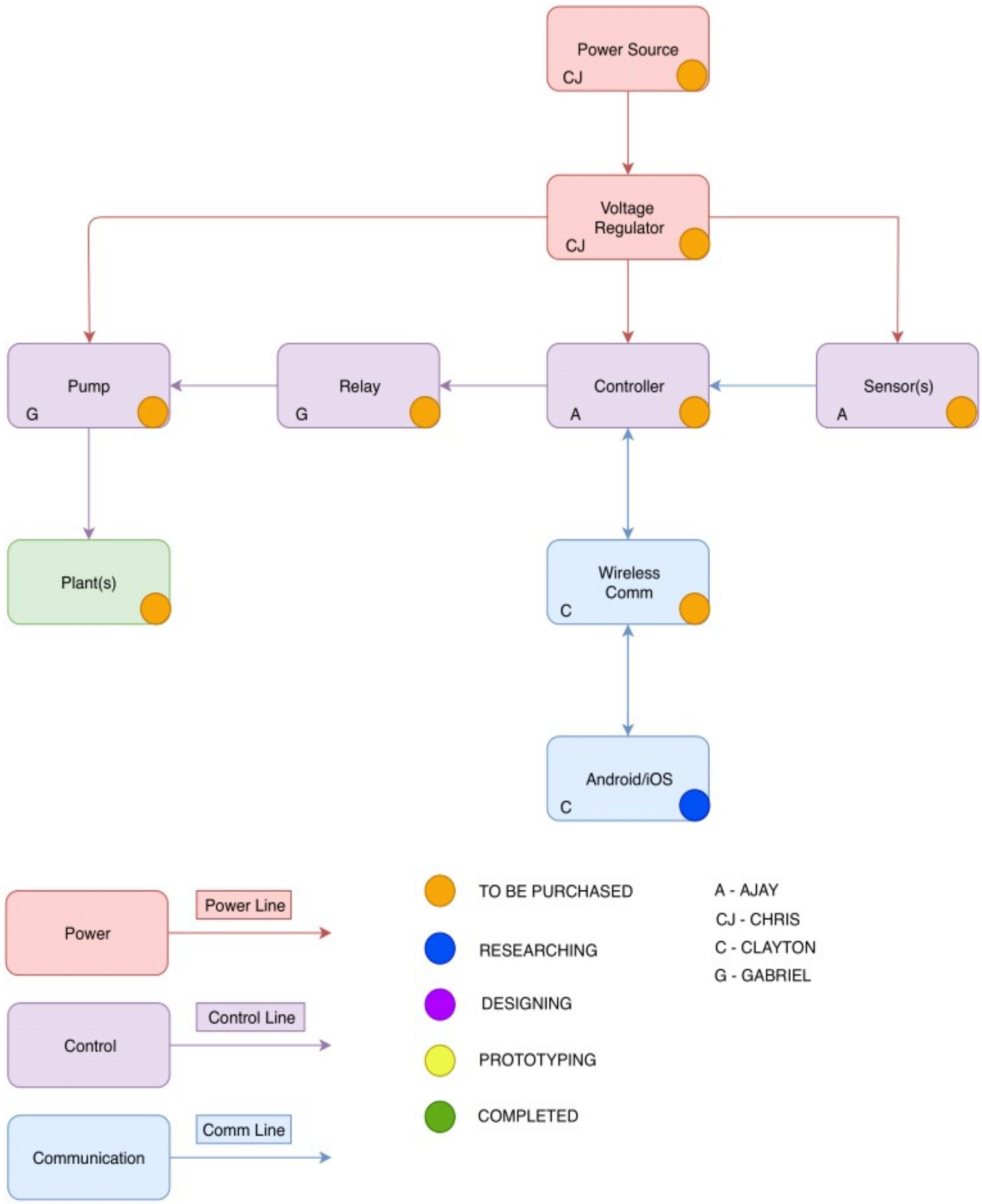


Figure 2. 2: Project Flow Diagram

2.6 Physical Design

After gathering ideas of different designs for the plant nanny, we all agreed on a design that will look sleek and modern. We want the plant nanny to have an eye catchy design. Where the user will want to put the plant nanny as a center piece to which ever room they decide. The plant nanny is going to be design as a rectangle box made of wood panels. This rectangle box is going to be the housing for the PCB, water pump, water reservoir, display screen, and all of the sensors.

The size for the housing is going to be depict by the size of the reservoir. We are looking for the right size reservoir that can go inside the housing but also large enough to hold at least 1 gallon of water. The water reservoir will have an easy access to refill the tank. The wall of the reservoir needs to be thick for durability. Also, the height of the reservoir will have to be as small as possible. In order to fit an 8 to 10-inch pot. Where the pot will sit right on top of the reservoir. It’s highly important to us to make this physical design easy to build and mobile.

The lighting fixture is going to be held by a metal flat rod. The metal flat rod needs to be strong enough to hold at least two pounds. The light fixture is going to be either held by magnets or just screwed to the metal flat rod. However, we are leaning more towards the magnets, which will give the user the ability to change the light fixture if necessary. The display screen will be mounted on the front panel of the rectangle housing, right at the center of the panel. See Figure 2.3, pictured below, for a rough draft of our physical device design upon completion of the project.

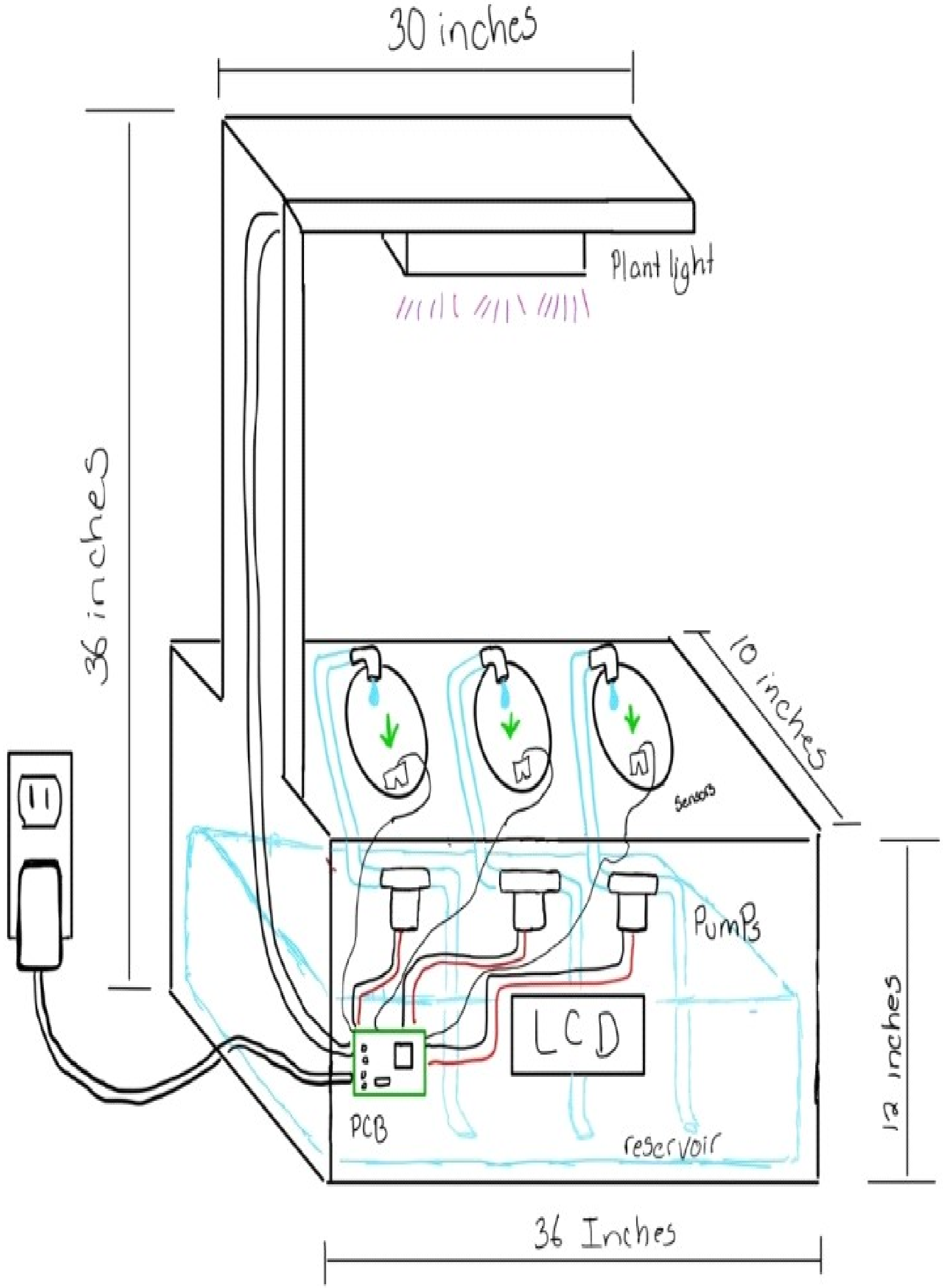


Figure 2. 3: Physical Device Design Draft

3. Research

The world today is constantly moving, and people are busier than ever before. People have so much going on in their day-to-day lives that some very basic tasks can become tedious, take up precious, allotted, time, and may even be forgotten throughout a typical day. With the advancement of technology, smart home automation is becoming front and center of this brave new world. With innovations of easy to use and easy to program controllers, such as the raspberry pi and Arduino boards, the accessibility to automation has never been made simpler. These new technologies have allowed companies and home users alike to create smart devices that have the capability to automate home gardens throughout today's world.

This section will go over the following:

- Existing similar products as well as some homemade do-it-yourself projects found on hobbyist web pages or forums
- The relevant technologies involved with the project and credible research about them
- Several comparisons about the types of technology in order to best select device components for our design
- Our selection of parts based upon the comparison research

3.1 Existing Projects and Products

An automated indoor garden is not a groundbreaking invention. Hundreds, if not more, of products are available commercially. All of which have their own unique design and features. Some may be as simple as a pot with hose hooked up to a water tank that has the ability to water itself. Others come in more advanced form factors holding several plants with grow lights and multiple sensors to alert the home user when the water reservoir becomes too depleted. Our goal is to achieve a healthy balance. Taking care of multiple plants that alerts the user with some helpful information about the plant and its relative atmosphere all while maintaining an aesthetically pleasing form.

Technology hobbyists and the do-it-yourself communities of the internet are no stranger to home-made smart innovations. Raspberry Pi and Arduino boards run rampant throughout young and old interested persons. The availability of these boards and the relative low cost to purchase them have made easier than ever to construct simple circuits and allow users of any age to program them rather simply. It works by connecting several sensors to these boards all of which allow the controller to perform a task or send the user useful data. This general idea is also how we will construct our device, but instead of using some of the bigger Arduino boards, we will be constructing our own PCB board with only the GPIO lines and sensors we need to utilize. Saving on space and unnecessary cables everywhere. Pictured below is an example make-shift home smart garden.

3.2 Relevant Technologies

The following section deals with technologies that are relevant to the proposed project and all of the research that was done on them. In any project it is important to review the relevant functions of the technology you plan on utilizing. It is an important part of the design process that will help narrow down the specific component necessary for the project.

3.2.01 AC/DC Conversion vs Battery

When it comes to powering our device, we generally arrive at two possible sources. Using multiple batteries arranged in either series or parallel with the rest of our circuit or using the power coming directly from a typical wall outlet. This section will compare the two in the scope of our design.

First, let us discuss the battery. Batteries are an excellent choice for stationary or mobile applications. The obvious benefit of being able to bring a device with you anywhere cannot be ignored. The first group of batteries to be discussed are those of a portable battery pack, otherwise known as a power bank. Power banks are small form factor batteries commonly found in handheld devices we use every day, such as our cell phones and tablets. Power banks are an extremely common and popular choice. They provide fast and portable charging to a consumer on the go. Power banks may consist of either a lithium ion or a lithium polymer battery. These batteries are designed to store charge in its ion or polymer battery, then once charged it can be used to provide that charge to a number of devices.

Lithium-Ion

The lithium-ion battery works by having two ends that are called electrodes. One end is the cathode (providing a negative (-) charge) and the other end is known is the anode (providing a positive (+) charge). The battery's main function is to store and release energy. It does this by forcing electrons to move from its anode to its cathode. This flow of electrons is the current. The energy created by this flow of electrons can be used by connecting the battery to any device in order to provide it power. The cathode is typically made from a metal oxide like cobalt oxide.

While the anode is usually made out of the element known as Carbon. Electrolytes sit between the electrodes inside of the battery. These electrolytes contain lithium ions. Once the battery is situated to power a device, the positively charged lithium ions from the anode end move to the cathode end, causing it to become more positively charged than the anode. The energy created by the flow of electrons powers the device because the current will first flow to the device, then to the cathode.

When the lithium-ion battery requires charging, we connect it to its dedicated charging cable. The lithium ions will now move in the opposite direction; that is: from cathode to anode. This is known as the recharge process.

The main selling point to these lithium-ion batteries are that they are rechargeable batteries. You will find lithium-ion batteries in a large number of applications such as: cell phones, tablets, laptops, etc. The lithium ion can produce a lot more electrical power per unit weight compared to some other types of batteries. This just means that you get more power in a much smaller form factor. This is a huge benefit to devices with small size constraints. These batteries also have the benefit of being a low-cost option to consumers.

The lithium-ion battery does come with some disadvantages as well. These battery types require special protection when it comes to controlling the voltage and current that flows through it. Over charging or over discharging could severely damage the battery and shorten its lifespan, or potentially damage it beyond repair. Another factor to consider is the number of cycles it goes through. Lithium-ions can age quickly, and all come with a certain number of cycles of charging and discharging it can handle. As the battery it ages it will begin to discharge faster and faster.

Lithium-Polymer

Another battery option that is used in a number of hand-held devices is the lithium polymer battery. The lithium polymer battery uses a polymer electrolyte in place of a liquid electrolyte. Like the lithium-ion, the lithium polymer battery is also rechargeable and has an ultra-thin like design. The lithium polymer battery does not require protection by a shell-like body and so can be a very lightweight and economical solution. These polymer batteries have the advantage of being more resistant to overcharging. In turn, this means that the chance of electrolyte discharge is lower. In addition, they can be manufactured in several sizes allowing a designer to fit them in multiple forms depending on the design constraints.

The disadvantages to choosing a lithium-polymer battery are that the manufacturing cost can be very high. The polymer batteries also have a much lower energy density than its lithium-ion counterpart, which means the polymer batteries cannot hold nearly as much charge.

Nickel Cadmium

The Nickel Cadmium or NiCad battery can also be considered for design projects. It is a type of battery that utilizes nickel oxide hydroxide and metallic cadmium as its electrodes.
Advantages of the NiCad batteries are:

- Rechargeable
- Fast charging
- High number of charge cycles
- Low charging temperature
- Resistant to overcharge damage
- Affordable

The NiCad battery also comes with its disadvantages:

- Low energy density
- Made from toxic materials
- Quick discharge rate
- Memory defect (battery will lose charge quicker than normal)

The NiCad battery cells used to be popular in a number of applications such as: power tools, photography equipment, flashlights, emergency lighting, R/C devices, and portable electronics.

Nickel-Metal Hydride

The Nickel-Metal Hydride battery or NiMH battery can be considered the newer updated version of the Nickel Cadmium battery and has largely replaced it. NiMH batteries was developed for advanced hydrogen energy storage and are used in devices where runtime is important. These NiMH batteries do not suffer from the memory defect of its predecessor and contain up to 40% more capacity. They are also not manufactured from the toxic materials the cadmium batteries were. Instead they are made from recyclable material which is an environmental benefit. Downsides to utilizing this battery in design is that they do generate a considerable amount of heat and can take a longer time to charge. They also tend to discharge rapidly when not in use and suffer from performance deterioration when operating in higher temperatures.

Lead Acid Battery

This battery technology is normally found in cars, trucks, and other automobiles. These are typically larger in size and exactly fit for portable or handheld devices. However, they do have a number of advantages:

- Rechargeable
- Simple to manufacture
- Inexpensive (cost/Watt)
- Low self-discharge
- Reliable
- Durable
- Low Maintenance
- No memory defects

The advantages are offset by:

- Large footprint (not suitable for small devices)
- Low energy density
- Limited amount of discharge cycles
- Improper charging can easily cause damage

Alkaline Battery

Alkaline batteries are last on the list of battery technology options. These are by far the most popular type. 80% of all batteries manufactured in the United States are alkaline batteries. They come in various sizes and are able to be used in a large number of household devices. These batteries are also rechargeable, but with a capacity approximately four times that of its nickel cadmium or nickel-metal hydride brothers. Alkaline batteries have the benefit of operating at a low temperature, safe for the environment, and can hold a charge for up to 7 years without even being used. These batteries do have disadvantages, though not as bad as its counterparts. Alkaline batteries carry a high internal resistance which means a low power output. If alkaline batteries are kept inside of its device for too long, it is possible that they will begin to leak some materials which can potentially damage the circuits.

AC Power

Next, we will consider the alternate power source for the project in question. Converting the alternating current (AC) from your typical wall outlet to direct current (DC). This power source is most beneficial to electronic devices that will remain stationary most of the time. If the device is not portable or being moved from place to place that often than there is no need for a more mobile supply of power. The electronic device can simply remain still, get constant power, and never have to worry about if the power supply will run out of juice under normal conditions.

There are drawbacks of course. Relying on your wall outlet power means relying on the power company for power. Inclement weather conditions and natural disasters can disrupt the connection from a home to the grid. If this were to happen than all power to the home will be completely cut-off. Including your device. In addition, a power spike or surge could potentially fry the electrical components of your devices. It is important to consider using a surge protector for all electronic devices that are relying on a wall outlet as a power source.

In order to utilize this power, we need to convert it from AC to DC. The block diagram pictured below (Figure 3.4) shoes the typical process of converting a 230 V AC Main to a regulated 5 V DC.

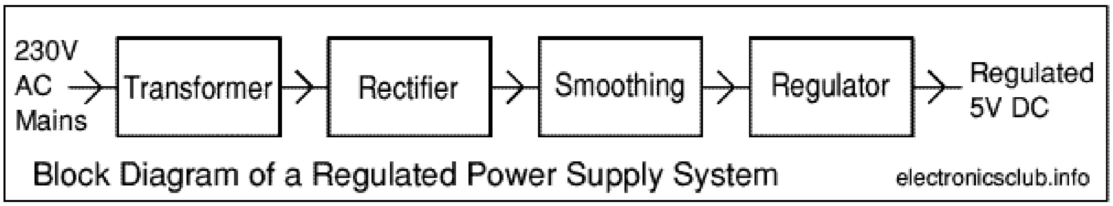


Figure 3. 1: Block Diagram of AC/DC Conversion

Source: https://electronicsclub.info/powersupplies.htm#transformer

After carefully comparing and contrasting each battery type and the option to utilize a wall outlet for AC/DC Conversion, we concluded that using a power adaptor to the wall is the best choice for our project. Because our project is being designed house more than one plant, have its own light source, and be of a bigger size, we feel that it typically will not be moved around as often as smaller competitor products. Using AC/DC conversion will allow a constant power source. The user will not need to worry themselves with battery charge levels or deterioration. You can see a brief comparison of all technologies discussed in the table below (Table 3.1).

Table 3. 1– Battery Types vs AC/DC

Power Type	Advantages	Disadvantages
Lithium-Ion	• Rechargeable • High energy density • Slow discharge • No priming • High current density	• Requires special housing • Ages quickly • Cost
Lithium Polymer	• Rechargeable • Thin design • Light weight • Several sizes • safe	• low energy density • high cost
Nickel Cadmium	• rechargeable • fast charging • high charge cycles • low temperature • affordable	• low energy density • toxic materials • quick discharge • memory defect
Nickel-Metal Hydride	• rechargeable • high capacity • recyclable materials	• heat generation • high charge time • discharges quickly • performance deteriorates • high maintenance
Lead Acid	• rechargeable • inexpensive • reliable & durable • low discharge • low maintenance	• large • limited amount of discharge cycles • environmental damage • improper charging
Alkaline	• rechargeable • 4x capacity of nickel • Slow discharge • Low temperature • Safe	• Heavy • Low energy density • High internal resistance • Material leakage
AC/DC	• Constant power • No deterioration • Safe • No discharge worries • Set it and forget it	• Not mobile • Surge/storm damage

3.2.02 Microcontroller

A microcontroller is a small, low-cost and self-contained computer-on-a-chip that can be used as an embedded system (elprocus.com). Microcontrollers are usually low power consuming and can be operated with just battery power. They can be located in almost any electronic device like cars, phones, and computers. As the name suggests they are “micro” controllers, a small electrical device that provide support to a larger device by controlling or managing the data required for the system to operate automatically. This allows a system to accomplish many things that a human could never do by themselves or assist in eliminating errors produced by the human’s actions. The microcontrollers are characterized regarding bus-width, instruction set, and memory structure (elprocus.com). The microcontroller that we will be selecting for our project must meet a few requirements that we have placed. This is because the microcontroller will automate our system and we wish it to be done in the cheapest and most efficient way possible. These requirements include a low-power mode, the method of input and output, and a fast-enough clock rate in order to execute gather data and execute instructions quickly.

Low-power mode

Since our plant growth system will not need to be active all the time, there must be a way to put the microcontroller to sleep reducing usage of the clock until the new instruction is to be executed. As frequency increases, the power consumption increases linearly with it. This is the basis of low-power mode, they generally involve disabling of certain circuitry or clocks that drives certain peripherals of the microcontroller so that power is saved (circuitdigest.com). There are four different types of low-power mode: sleep mode, standby mode, deep sleep mode, and OFF mode.

Sleep mode is the simplest of the low power modes. In this mode, the microcontrollers (MCU) high frequency primary clock remains running while the clock tree that drives the CPU circuitry is turned off. This enables the microcontroller to return executing instruction at a very fast rate when the wake-up trigger is sent. However, it is not the best energy saving mode if it is expected that the device will constantly wake up from sleep mode. This is because there is a high-power consumption for the MCU to wake up and return to active mode so quickly

Standby mode is another low power mode that involves turning of the clock for the CPU. In standby mode, high frequency peripherals like direct memory access (DMA), high-speed serial ports, analog-to-digital and digital-to-analog converters, and AES encryption/decryption remain active so that they are available for use as soon as the CPU is woken up. Sometimes the MCU keeps the RAM active as well and can be accessed by the DMA, allowing for data storage and retrieval without the intervention of the CPU. A low power MCU in this mode can go as low as 45 μA/MHz.

Going into deep sleep mode will save even more power. In deep sleep mode the MCU disables all the high frequency system clocks and other unnecessary circuitry. Only the MCU oscillators for critical elements including the watchdog timer and the real time clock (RTC) are kept active. Some of the microcontrollers may add other elements to the list of peripherals to keep active. For example, LCD drivers and touchscreen interfaces may remain active so that the CPU is not woken up unless absolutely necessary. In order for the MCU to resume executing programs from the correct point upon waking up, the RAM and CPU registers are completely saved to memory. In this mode, power consumption of the MCU can go as low as 1 μA. the downside of turning of all the high frequency clocks is that MCU can take a longer time to return to active mode, the wake-up time could range from 5 μs up to 8 μs.

Some of the microcontrollers have a final and fourth energy saving mode called the stop/OFF mode. In the OFF mode, all the high frequency and low frequency oscillators are disabled leaving only critical elements of the MCU active. But according to embedded.com Sometimes the MCU may also preserve the state of the MCU's pointer and configuration registers may be preserved depending on the tradeoff between static power consumption and wakeup time. See Figure 3.5, pictured below.

The features of all the sleep modes mentioned above differ from MCU to MCU but the general rule of thumb is; the deeper the sleep, the more the number of peripherals disabled during sleep, and the lower the amount of power consumed, although, this usually also means; the higher the amount of energy consumed to get the system back up (circuitdigest.com).

Microcontroller Communication

There are many standards by which MCU's take in input from the user or the environment and generate an output. There are three common types of communication peripherals that we want to choose from that the microcontroller will have by which it receives input and generates output. They are SPI, I2C and UART.

UART

UART stands for universal asynchronous receiver and transmitter. It is a simple protocol that allows the microcontroller to communicate with serial devices. The UART system communicate by taking bytes of data and transmits the individual bits in the byte in sequence. At the destination, the receiver will receive all the bits, reassemble the bits into bytes and it will then have the data that was sent. The idle state or the no data start is high voltage and will start with a low voltage for the start bit, to indicate that data is coming. When the receiver detects a high voltage again that means it has reached the stop bit and no more data is coming. Since it’s an asynchronous communication, no external clocks are needed to synchronize the data. This will reduce the number of pins used but will require more precision to transfer data carefully. All the hardware is controlled by an internal clock that is 8 or 16 times the bit rate, the rate at which bits are transferred.

I2C

I2C stand for inter-integrated circuit. Like UART, it is a serial communications protocol for microcontrollers. according to maker.pro While this peripheral is almost never used for PC-device communication, it is incredibly popular with modules and sensors, making it useful for projects that require many parts working together. In fact, I2C allows you to potentially connect up to 128 devices to your main board! It uses a master slave system where the microcontroller is designated as the master and the connected devices like the sensors and drivers are the slaves.

I2C uses a shared address and data bus so the devices use the same wires in order transmit information between devices. This means that it is a synchronous operation, so it uses separate lines for data with a clock to keep the connected devices in sync.

SPI

SPI stands for serial peripheral interface. like i2c and uart, spi is a communication protocol design for microcontrollers so that they can communicate with each other. Similar to i2c, spi uses a master slave format for the communications between devices. But unlike i2c where multiple masters and slaves can be connected, spi allows for a single master to connect to multiples slave devices up to a maximum of 4 slave devices. It is also much faster than i2c. See the figure below (Figure 3.8) an illustrative example.

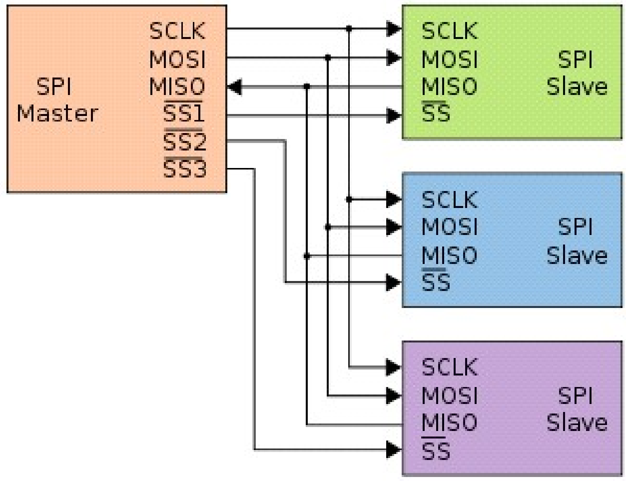


Figure 3. 2: Single Master to Multiple Slaves

Source: Colin M.L. Burnett (CC BY-SA 3.0)

The table below (Table 3.2) compares the different communications.

Table 3. 2 – Comparison of Communication methodologies

SPI	**I2C**	**UART**
• Synchronous communication • Uses Less power than I2C	• Synchronous communication • Only 2 wires for communication	• Asynchronous communication • Most popular • Allows for error checking
• Simple (no processing overheads) • No error checking protocol	• Easy to add extra devices to the bus • Circuit easily becomes more complex • Possibility of address conflict	• More suited toward communication between two devices • Limited to 8 bits/transmission
• Supports Full Duplex communication • Not limited to 8 bits/transmission	• Slow speed of transmission	• No internal clock

Clock Rate

Clock rate is the frequency at which the microcontroller operates and is usually an indicator of how fast the MCU can execute instructions. It's the number of pulses generated by a crystal oscillator and is used to set the base processing speed and period of the microcontroller. Since we are not using calculation intensive instructions for our project, a few 10s of MHz of clock rate is enough. As discussed above in the section about sleep modes we want to minimize the clock speed as much as possible so that we can use less energy to run the system.

Microcontroller General Purpose Input/Output

The microcontroller has what is called general-purpose input and output ports. These ports relate to several pins located on the microcontroller. Connected to these pins are various sensors for the project at hand in which we are designing. These sensors will take data is input, then pending on this data our microcontroller will output or 'do' something that has been preprogrammed.

The general-purpose input/output, or GPIO ports, typically have eight pins that handle input and output. The user typically has the freedom to set these pins as input or output. None of these pins are permanently set by the controller itself. GPIO pins allow peripherals to be added to the device which in turn increase the functionality of the microcontroller on the PCB.

General purpose ports handle either high or low voltages. They use ones and zeroes to represent these high or low voltages. Physical components or sensors, such as the temperature sensor we plan to use in this project, only deal with voltages. This is known as analog. The controller's responsibility is to convert this analog data to a readable digital format, commonly called analog to digital conversion. It takes the analog voltage sent to the microcontrollers corresponding pin and converts it into a digital representation of a zero (low) or a one (high).

Arduino Uno is one bard that offers GPIO and is commonly found on development boards for testing purposes. The Uno board acts as a source of communication between every important component of the system. Several important things to consider when using the Arduino board are as follows.

- All GPIO pins have a default voltage signal of 5V

  This means that by default all Arduino Uno GPIO's will read as a 5 V signal or 'high'. The 'LOW' reading would then indicate a voltage of 0 V

- The Arduino Uno IDE cannot be programmed to change the voltage to 3.3V

This is important because many of the components we plan on using in this project require a smaller voltage than 5 V, 3.3 V to be exact. If we test our components without doing something about this, we will severely damage the components and they will not be able to be used in our design. In order to work around this our team will be forced to come up with creative solutions for testing. By building different circuits on the breadboard and connecting to the GPIO as input, we will safely be able to use our components. In the overall design a voltage regulator will be used. The use of a voltage regulator provides more reliability and safety. While we could design our own circuit with the use of resistors and Zener diodes for the overall product, the voltage regulator achieves the same result with a smaller footprint. Also, the circuit design could potentially the current passing through all those resistors and didoes could impact the longevity of the design.

Microcontroller Architecture

The computer architecture is a design that causes processors to use the layouts of their internal components to become more efficient and also faster. Two common types of architectures are used today's world:

- Complex Instruction Set Computer (CISC)
- Reduced Instruction Set Computer (RISC)

CISC

The CISC architecture mainly relies on the functions of its hardware to complete its program or task. Because of this, the number of lines or instructions of assembly code is considerably reduced. Instead, CISC relies on simple instructions that are formed in a way to make more intricate instructions. This can be seen in a multiplication function that will use ordinary 'add' and 'shift' instructions without having to type them out.

The advantage of using CISC is that it has a multi-clock cycle which allows for a quicker execution of code since it has such a lower amount of lines. The drawback here is the amount of space. The more complex simple instructions utilize much more memory which translates to less space available for other functions such as communication or GPIO ports.

RISC

In contrast, RISC veers toward the use of more lines of code, but more simpler instructions as well. This allows RISC to rely more on its software to perform tasks. The clock design in RISC is that it only has one clock but has a smaller clock that executes one instruction per clock cycle.

In opposition to the CISC architecture, RISC allows for more space for other functions you might need to incorporate with the GPIO lines.

As you can see each form of architecture is good for different scenarios. Doing this research was important as we wanted to make sure what we chose supported our design purposes. There are many factors to consider when deciding on every component for this project and this is just one more to the log list of factors. The table below (Table 3.3) displays the differences of each architecture more simply.

Table 3. 3 – RISC vs CISC

CISC	RISC
Hardware based	Software based
Less registers utilized	More registers utilized
Multiple cycles to execute 1 inst.	Instr. Executed in one cycle
Many instruction sets	Small amount of instructions To create more complex ones
Uses microprogramming to convert languages	Conversion of languages Added in compiler

For the tasks and functions of the project our team is designing, it is clear that RISC is the correct choice for us. The reduced instruction size will help in the sense that the size of our chips we select will be smaller than that of the CISC counterpart. CISC chips instructions require extra hardware. This would not pair well since our chip already has to do things such as storing/writing/reading data and using outputs to drive a water pump. This research is beneficial to us when researching and deciding upon a microcontroller for use with our project.

3.2.03 Sensors

One of the most important aspect of our project is that the user is aware of the conditions of the growth system. The system needs to be able to send timely alerts to the user to ensure a hospitable environment with adequate resources for the plant. To this end we outfit the system with an array of sensors that will measure its current state and relay this data to peripherals for adjustments of the systems functions.

The sensors will lookout for factors such as the humidity of the surrounding, the moisture content of the soil, temperature of the surrounding, water level of the reservoir, and the light intensity. The sensors output will be connected to an analog or digital input pin and go through an analog to digital converter if required, before being sent to the microcontroller. These sensors will be located outside the plant housing. For an indoor plant growth system, we determined the usefulness of many different types of sensors, eventually narrowing down the list to just the 5 mentioned above.
These sensors will be mounted outside the housing system for a clearer more accurate reading. As such one of our main objectives when selecting sensors was to minimize size and weight of the sensors. Since we will be powering our system through a power outlet, we could afford some sacrifices within that area.

3.2.03.1 Water Level

One of the major steps we needed to take when automating our plant growth system was making sure the plants were adequately hydrated at proper intervals. The water reservoir that comes together with our system will store the water needed for this purpose. However, the human element cannot be eliminated from ensuring that the reservoir is always filled with an adequate amount of water for the plants. To minimize the human involvement with the project, we will integrate a water level sensor/indicator so that the reservoir is refilled only when it is necessary. There are 4 different methods for detecting the water level in the reservoir, described in the following paragraphs, that we feel could be used to fulfill the task.

Multiple Metal Probes

In this method, 5 metal probes are placed at different percentage points of the reservoir as seen in Figure 3.9. the other end will then be connected to an I/O port on the microcontroller. These probes will be used to detect if water is present or not at the point where the probes are placed by taking advantage of the conductive property of water. A current is sent through the water from the bottom of the reservoir and the microcontroller will check the maximum level at which the probes pick up the current. This information can then be sent wirelessly to the user through the accompanying mobile app.

One of the pros of using metal probes for our project is that they are simple to understand and easy to code the microcontroller for. It will also give the satisfaction of using a self-made method instead of a commercial water level sensor. The disadvantages of this method include that microcontrollers will need to have many I/O pins to receive input from each of the probes. Another major disadvantage will be that the metal probes will be immersed in water for long durations, resulting in corrosion and other chemical reactions that could damage the probes and/or the plant. We estimate that buying all the parts to build this sensor could total to become the most expensive of the 4 methods.

Ultrasonic Sensor

Ultrasonic water level sensors emit an ultrasonic wave of high frequencies that then get reflected by the target. By recording the time taken for the sound wave to travel to the target and bounce back we can use the equation below to determine the distance it traveled.

$$Distance = \frac{Speed\ of\ Sound\ *\ Time\ Traveled}{2}$$

In this equation, we can let *speed of sound* to be the speed at which sound travels through air which is 343 m/s.
An issue that we found with these types of sensors is that they have a limited sensing range, usually between 2 cm to half a meter. However, they are very simple and easy to implement compared to using multiple metal probes. Ultrasonic sensors are very cheap and can be commonly found on the market for less than $4. Since the sensor will never come into contact, it has the added advantage of being corrosion proof unlike typical water level sensors. With the speed at which sound travels in air, ultrasonic sensor can gather data very quickly, but it is still slower than some of the other sensors. Our group all agreed that ultrasonic sensors may the most cost-efficient method of them all.

Resistive Sensor

Resistive water level sensors are sensors that use the changes in its resistance to measure the height of the water in the reservoir. They work by inserting two metal plates of different lengths into the reservoir making sure to keep in contact with the water. The longer probe will carry a low voltage current that travels through the water and is picked up by the second probe. The more water there is between the plates, the lower the voltage between the two plates and the lower the resistance. Because resistive sensors take advantage of the conductive property of the water to work, they can also be called conductive sensors.
Since the sensor uses a very voltage current it is safe, but it would still not be recommended to place your hand in the reservoir to avoid any mishaps. Another advantage of resistive sensors is that they are easy to use and implement into the project. They are cheap and is usually in stock on markets making for purchase. The major disadvantage these types of water level sensors have is that they have exposed metal plates immersed in water. Without regular maintenance the plates could contain build up that would affect the performance of the sensor. over time, chemical reactions between water and the metal probes could cause corrosion and damage the sensor or influence the plants growth.

Visual Indicators

The final method by which we can alert the user to the water level in the reservoir is by using visual indicators. These indicators could be physical markings on the reservoir itself, representing the amount of water left or a long slender tube that floats on top of the water. The tube will protrude out of the reservoir at different heights to indicate the water level to the viewer, like the inner mechanisms of the *Self Watering 5" Pots with Water Level Indicator* shown below in Figure 3.10.

The advantage of using a visual indicator for the water level is that they are extremely cheap and easy to implement. With one glance a user could estimate the water level in the reservoir and decide whether it is time for a refill. It requires no electrical power to operate making it the most energy conserving method of them all. The downside is that it would not be possible to alert users remotely about the water level.

Table 3.4 below lists a summary of the advantages and disadvantages of the four different types of water level sensor for our project.

Table 3. 4 – Water Level Sensor Comparisons

Methods of Measuring Water Level	Advantages	Disadvantages
Multiple Metal Probes	• Easy to understand and implement • The satisfaction of building it yourself • Can connect to microcontroller and send result to user	• Cost of parts could total to become most expensive • Probes will corrode over time • Require a microcontroller many I/O pins for all the probes
Ultrasonic Sensor	• Very cheap and easy to find • Easy to understand and simple to implement and use • Will not be corroded because it will not touch the water • Can connect to microcontroller and send result to user	• Has a limited detection range of between 2 cm to 0.5 m • Slower than most other types of sensors
Resistive Sensor	• Cheap and very easily found for purchase • Low voltage current makes it safe to use • Can connect to microcontroller and send result to user	• Requires regular maintenance to remove build up • Has exposed metal plates that corrode over time and damage sensors • Damaged sensors could affect plant growth and require replacement
Visual indicators	• Cheapest and easiest to understand • Simple and quick to implement • Requires no power to run making it most energy efficient	• Requires regular monitoring by the user • Cannot be used to send the result to the user remotely • Requires the indicators to be clear and conspicuous for ease of access

Moisture Sensor

A soils water capacity is the maximum amount of water available for a plant to use that the soil can provide. The soil holds varying amounts of water by storing them in the pores between soil particles. This amount of water plant-available water in the soil is determined by the diameter of the soil pores. If the soil contains inadequate amounts of water for the plants, they could starve and die. On the other hand, overwatering the plant will drown the roots making them unable to take in oxygen, leading to their doom. Our project will aim to find the optimal watering times and duration by using a soil moisture sensor. There are 3 different types of soil moisture sensors that we are considering integrating into our system, they are two-legged resistive soil moisture sensors, compact resistive soil moisture sensors with no legs, and capacitive soil moisture sensors.

Two-Legged Resistive Sensor

The two-legged sensor uses a two-legged Lead that is inserted into the soil to test moisture content. It has two header pins at the other end of the sensor that will be connected to an amplifier and then to the microcontroller. This type of sensor is designed to estimate soil volumetric water content based on the dielectric constant (soil bulk permittivity) of the soil. The dielectric constant of soil will increase or decrease as the water content of the soil changes. This is because the dielectric constant of water is much larger than the other soil components, including air. Therefore, by measuring the dielectric constant of the soil we can estimate its moisture levels.
The advantages of this type of soil moisture sensors is that they are fairly common to find and simple to integrate into the project. It is the cheapest type of soil moisture sensor compared to the other two. the major disadvantage for this type of sensor lies in the fact that it measures the dielectric constant of the soil by sending a DC current through one of the legs. Because we expect the sensor to be placed inside the soil for an extended period of time, the DC current and water will eventually corrode the legs. This would require that the sensor be replaced occasionally in order to prevent it from affecting the plants.

Compact Resistive Sensor

This type of sensor is like the two-legged soil moisture sensor. It will measure the water content in the soil by measuring the dielectric constant of the soil. The compact sensor uses multiple pairs of copper paths to emulate the two legs. this sensor type is also typically found on the market but at a slightly higher price. Since compact sensors work similarly to two-legged sensors they possess similar advantages/disadvantages as the latter. However, unlike the first type of sensor, this one can be directly connected to the microcontroller and is more energy efficient.

Capacitive Sensor

A capacitive soil moisture sensor works by measuring the changes in capacitance caused by the changes in the dielectric. Capacitive measuring basically measures the dielectric that is formed by the soil, and the water is the most important factor that affects the dielectric [2]. As the moisture level changes, so does the capacitance of the dielectric and it produces a voltage proportional to the capacitor in the soil. This voltage is then converted to a digital signal that can be used to determine the soil moisture levels.
The greatest advantage of a capacitive sensor is that there are no exposed metal paths. This means that they will not come into contact with the soil and thereby prevents the chances of the sensor being corroded. It can also provide more accurate data regarding soil moisture levels compared to the 2 resistive sensors. the disadvantage though is that it has more onboard electronics making it more expensive compared to the other sensor types. it is also not as common as the other 2 and a quick preliminary search resulted in only a couple different capacitive moisture sensors.

Table 3.5 (see below) provides a summary of the advantages and disadvantages of the three different types of soil moisture sensors.

Table 3. 5 – Soil Moisture Sensor Comparisons

	Two-Legged Resistive sensor	Compact Resistive Sensor	Capacitive Sensor
Price	$1 to $3	$3 to $6	> $10
Advantages	• Simple and easy to implement • Cheapest • Fairly common on the market	• Simple and easy to implement • Cheap • Fairly common on the market	• Simple and easy to implement • Resistant to corrosion of the sensors metal plates • Can gather more accurate readings
Disadvantages	• Susceptible to corrosion of the exposed metal plates on the sensor • Measurement is Less precise	• Susceptible to corrosion of the exposed metal plates on the sensor • Measurement is Less precise	• Expensive • Not too many different capacitive sensors on the market

Temperature Sensor

Temperature sensors are very important feature of our project. The temperature sensor will provide a measurement of the ambient temperature of the plant's environment. This information will allow the device to adjust the watering cycle of the plant accordingly. The temperature sensor will help the project to regulate water consumption and reduce wasting resources. By adjusting the amount of times required to irrigate the plant at varying temperatures.

For maximum efficiency of our system we look for temperature sensors that are low cost. Ideally our sensor would be able to sense a wide range of temperatures for the extreme cases. However, considering that the temperature in the average household is somewhere between 60 - 70 °F (15 – 21 °C) for which our project was designed, the temperature sensor need not be sophisticated.

Humidity Sensor

Plants use their leaves to “breathe” by opening and closing their stomata, small pores on the leaves. By transpiring, the plant can lose some water and this water will gather in the air and raise the relative humidity. Relative humidity is the amount of water vapor in the air compare to the maximum water vapor that it can contain. When the relative humidity gets too high, there can be a lack of air for the plants to use for photosynthesis. After an extended period of this, plants will naturally suffocate to the lack of air flow and rot. Our project aims to keep track of the relative humidity in the plants environment so that their growth will not be affected. the sensor will measure the relative humidity in the air and alert users if it is outside the optimal range.

Light Sensor

Photosynthesis is the process by which plant and other organisms convert light energy into chemical energy. It is through photosynthesis that plants can synthesize their food using light, carbon dioxide and water. The amount of light needed for the process of photosynthesis to occurs is within the light waveband of 400 to 700 nm. Too much light can burn the plant causing it to lose water quickly and too little will make the plant malnourished therefore it is necessary to maintain a proper amount of light for the plant to grow well. In order for our plant growth system to maintain the light needed, we will integrate a light intensity sensor into the system. The optimal intensity varies along with the growth stages of a plant so we will use the average growth cycle of an indoor plant as the reference. At each perceived stage of the plant our system will adjust the light intensity so that the plant can grow well. The major concerns we face with using the light sensor is calibrating it so that the ambient light does not affect the data. Placement of our light sensor is important too; we want to place it so that it is not shaded by the plant.

3.2.04 Wireless Communications

Our project will be designed so that it can wirelessly communicate with the user. It must be able to send information detailing the current status of the plant growth system to the user. The user can then determine their next course of action so that the plant growth system can keep functioning properly and fulfill its purposes. Our project will send this information to the user using wireless communication methods that will be integrated into the microcontroller. There are multiple different wireless networking technologies that can be integrated into the system and they each have their advantages and disadvantages. For our projects purposes there are three main types of wireless network technologies that we can consider using, these are Wi-Fi, Bluetooth, and wireless home automation protocols. Of the many different wireless home automation standards, there were two that stood out and could make excellent alternatives to Wi-Fi and Bluetooth, they are ZigBee and Z-wave.

Wi-Fi

Wi-Fi is the popular name of the technology that uses radio frequency (RF) technology to provide high speed wireless internet and network connections. It is thought that Wi-Fi is an abbreviation for “wireless fidelity”, however it is simply the phrase used to refer to the wireless networking technology that is based of IEEE 802.11.

the Wi-Fi networking standards will transmit messages from one device to another by broadcasting electromagnetic radio waves and alternating the radio signals. The frequency at which the electromagnetic radio waves oscillate (the RF) varies between 3 kHz and 300 GHz. In this range, the various wi-fi standards operate within the frequencies of 2.4 GHz and 5 GHz. When the frequency of the wi-fi signals are increased, the rate at which data is sent can be increased but the range will drastically decrease. Wi-fi can directly send this data to the user’s device when it is in the range of roughly the size of a small building. When users are outside this range and provided there is an internet router in wi-fi range, our project can send the data to the user anywhere in the world using the internet.

Bluetooth

Bluetooth is a wireless technology standard that is used for communicating and exchanging data between devices such mobile phones and computers over short distances. It uses a 2.4 GHz frequency similar to other wireless technologies, creating a wireless network in a 10-meter radius. Compared to wi-fi, Bluetooth is cheaper, easier to setup, and has a lower consumption of energy. This makes it a very appealing for a low-cost project like ours. The very small range of 10 meters of Bluetooth is however the most detrimental point regarding our system. There are still parts of the project where it is possible to integrate Bluetooth like wireless communication between the system and its peripherals. Another not so obvious downside is that since Bluetooth operates at a frequency of 2.4 GHz, other wireless technologies would interfere with its signal. For example, wi-fi which has a frequency ranging from 2.4 GHz to 5 GHz would disrupt Bluetooth signals since the 2.4 GHz is the most widely used band for wi-fi. Even still Bluetooth is a cheap and easy to implement choice for our project

ZigBee

According to digi.com ZigBee is a wireless technology developed on a global standard to address the unique needs of a low-cost, low-power wireless IoT networks. Zigbee is based on the IEEE 802.15.4 specification and is used to create wireless personal area networks (PAN) and gained ratification in the year 2003. According to the Wikipedia The IEEE standard 802.15.4 intends to offer the fundamental lower network layers of a type of wireless personal area network (WPAN) which focuses on low-cost, low-speed ubiquitous communication between devices. As a result, ZigBee retains the advantages of being both low cost and consumes less power, making it a viable alternative to other wireless communication technologies like wi-fi and Bluetooth. Additionally, communication through ZigBee is secured because it takes place in an encrypted network. The ZigBee standard has two types of encryption models, the centralized security model and the distributed security model. The centralized security model uses a separate device that is responsible for securing the communication in the ZigBee standard called the trust center or the network coordinator. The distributed security model of ZigBee is simpler and uses a distributed network of routers. The routers authenticate other devices by sending the network key to them. The network key is what is used to encrypt the messages and all devices within the same network will have the same network key. in the united states of America ZigBee operates at a frequency band of 915 MHz. this means that ZigBee has a lower rate at which data is transferred compared to wi-fi or Bluetooth which operate at much higher frequencies. The speed at which data is transmitted is approximately 250 Kbit/s, but for the purposes of our project this speed is adequate. Another major disadvantage that ZigBee possesses is that it has limited range 10 to 100 meters. But with the introduction ZigBee 3.0 this limit can be surpassed by connecting the network to the internet. This way the user would be able to receive notifications from the system anywhere in the world.

Z-Wave

Z-wave is wireless communication technology primarily used for wireless home automation. It was developed by a Danish company named Zensys in 1999, it was introduced by Zensys as a light control system which eventually became the z-wave protocol. North America began gaining popularity around the year 2005 when 5 different companies came together to form the z-wave alliance. The objective of the alliance was to promote the z-wave technology and make all the products of the companies within the alliance able to operate with one another.

The z-wave wireless technology is designed to provide reliable way of transferring small data packets between devices. It uses low-energy radio waves to send these data packets. It operates on a radio frequency between 800 to 900 MHZ meaning it is very likely to avoid interference with other wireless communication technologies such as wi-fi or Bluetooth. Since there is less of a chance to witness interference on this frequency band, the data will travel faster and will have less congestion. Z-wave is a major competitor for ZigBee, another wireless home automation we are considering using in our project. Compared to ZigBee, z-wave is easier to setup up but both of them can’t communicate together so if we do decide, it will not be any combination of the two.

The disadvantages that we face when using z-wave technology is that z-wave has a very limited range of 30 meters between devices. Not only that but walls and other obstacles can reduce the size of this range. But if an internet router is within range of the z-wave network then it is possible to link the network to the internet allowing for users to receive data from anywhere in the world that provides internet. Another downside depending on how it is perceived is that a single z-wave network only supports 232 different devices. Of course, for the purposes of our project this limit is acceptable and more than enough. Along with new security standards, the z-wave is a very viable option as a wireless communication technology for our system, no worse than ZigBee, wi-fi, and Bluetooth. The table below (Table 3.6) displays a table of comparison between each technology.

Table 3. 6 – Comparison of Wireless Technologies

Wireless Technology	Advantages	Disadvantages
Wi-Fi	• Provides high speed communication • Can stay connected to anywhere in the world through internet • Simple and convenient to integrate with a network	• Signals can witness interference causing connectivity issues • Is insecure and vulnerable to malicious attacks • Has a limited signal range
Bluetooth	• Cheap and easy to setup • Low energy consumption	• Insecure and vulnerable to malicious attacks • Extremely limited range of 10 meters • Potential interference from other wireless technologies on the same frequency
ZigBee	• Highly reliable, simple, and is low cost • Low energy consumption • Secure communication due to encryption	• Requires multiple transmission for large data • Limited range of 10 – 100 meters
z-Wave	• Reliable and very easy to setup • Low energy consumption • Less likely to witness interference from other wireless technologies • Communication can be secured with new security standards	• Requires multiple transmissions for larger data • Limited network range of 30 meters

3.2.05 Lighting

One of the major components in creating this plant nanny was knowing what light to use for the plants to grow. Since the plant nanny is for indoor planting, we had to mimic everything the plant experience outside in the natural sunlight. There are different types of light that helps the growth and high yields for plants. The sunlight that plants consumes contains the complete spectrum of light like the colors in a rainbow: red through yellow to blue and violet, which also creates a balance of cool and warm light. Plants uses light in all ranges both higher and lower wavelengths. For example, ultraviolet and microwaves. The most important light for the plant seeding stage comes from the blue side of the spectrum. However, for the plants blooming and fruiting phase requires the orange to red side of the spectrum. For this project is important to know all the different types of grow lights that are available on the market. Also, understanding the efficiency, energy consumption, and photosynthetic benefits is extremely vital. Overall, understanding all these different types of features will decide which will be the best suitable lighting for the Plant Nanny.

HPS Lights

First of HPS grow lights, which stands for high pressure sodium lights, are known to be the most used for indoor planting over some decades. These lights are usually used in commercial greenhouse industry.

HPS lights are in the yellow to red range of the spectrum which wavelength is from 560-700 nanometer. From the figure, one can see the yellow light begins around 560nm and ends around 590nm. The orange light wavelengths are between 590 and 625 nm, while the red-light wavelengths ranges from 625nm and 700nm.

HID Lights

HID lights are another type of light use for growing plants, but they are not that useful. These lights work by having a gas filled tube and having electricity pass through it. HID stands for high intensity discharge lights and they are usually the brightest lights used for planting. One of the benefits of using HID lights is because of their brightness one can easily inspect the plant or crop. These lights were the standard lights to use a few years ago because they are approximately 10 times more efficient than the traditional incandescent light. However, by today’s standard growers are moving away from using HIDs.

LED Lights

One way of mimicking this sunlight is the use of LED lights. LEDs are light emitting diodes that create light when a flow of current passes through diode.

These lights are commonly used to grow plants indoors. NASA use LEDS to help produce crops that are edible in space. Different LEDs help produce the balance of cool and warm light that the natural solar spectrum produces. Below is a table (Table 3.7) that depicts each LED light and the affect it has on the plant.

Table 3. 7 – LEDs & the effects on Plants

LEDs	Effects on the plant
White 65000k	Enhance photosynthesis
Infrared 730-735 nm	Good for flowers and fruits
Ultraviolet 390- 395 nm	Seeding and sterilization
Blue 640-470 nm	Triggers growth and boost photosynthesis
Red 620-660 nm	Enhance blooming and fruiting

Sulfur Plasma Lights

Even though LED lights extremely effective in growing plants, the sulfur plasma lights are a new phenomenon for growing plants indoor. This new technology is known to emit light in frequencies and wavelengths nearly to that of the sun. It was reported by some researchers that the efficiency goes as high as 70 percent. However, the cost of this technology is expensive so for this project is definitely out of the question.

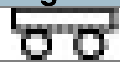
Lighting Height

Each plant requires a different amount of lighting. Mainly, most light fixtures that are used for growing plants indoors, cannot over exceed the amount of light needed for most plants. Plants that can acclimate to the settings indoor generally are split into three general categories: low, medium, and high light intensities. These categories typically signify the minimum of light required. Growth is generally best at the higher end of these suggested light ranges. The measure of light intensity or brightness is called a foot-candle. This measurement is the amount of light received by a 1 square foot surface that is 1 foot away from a light source.

Low-Light Plants

Low light intensity plants usually receive within 50- and 250-foot candles. For artificial light, some plants in this group can be maintained at as little as 10 foot-candles. Fluorescent lights are used for low light plants. Using these lights, low light plants should receive within 10 to 15 watts of fluorescent light per square foot of growing space. A single 2-foot 20-watt or a 4-foot 40-watt fluorescent tube can provide enough light for plant in this category. This is shown below in Table 3.8.

Table 3. 8 – Light output based on fixture type

Distance (feet)	Light output (foot-candles)‡ based on fixture type		
			
0.5 foot	500	700	900
1 foot	260 (200)	400 (260)	600
2 feet	110 (100)	180 (150)	330
3 feet	60 (60)	100 (90)	
4 feet	40	60	100

All lamps are standard 40-watt tubes. Output in parentheses is measured 1 foot on either side of a line directly below the lamps.

Medium-Light Plants

Medium light intensity plants prefer 250 to 1,000 foot-candles. Best growth occurs above 750 foot-candles unless plants also receive extended periods of direct sunlight. Give them artificial light in the 500 to 1,000 foot-candle range, or 15 or more watts per square foot of growing area. Although plants in this group can be held in the 250 to 500 foot-candle range, growth is best with more light. A fixture containing two fluorescent tubes is sufficient for plants in the low- to medium-light range. Adjustments in the number of tubes used may be made if you regulate the distance between the tubes and plants.

High-light plants

Plants that require high light intensity generally are less satisfactory for growing under artificial lights in the home. However, if you want to try, use special high-intensity lamps. These plants need at least 1,000 foot-candles, or 20 watts per square foot of growing area, but should have higher intensities for best growth and flowering. Fixtures containing three to four fluorescent tubes are necessary for plants requiring high light intensity.

Most plants should be located with the tips of the plants 6 to 12 inches from the light source. The intensity of light drops rapidly as the distance from the light bulbs or tubes increases. Table 1 shows this reduction of light intensity with distance below and to the side of tubes. Fluorescent tubes do not produce as much light at the ends as they do in the center, so the brightest spot under a fluorescent fixture is directly beneath the center of the tubes.

In most cases, plants receiving no outdoor light should be lit from 16 to 18 hours each day. If some additional light is received, 12 to 14 hours each day may be adequate. Lights should be used at the same time that plants receive window light. Using lights at the beginning or end of the day will not usually be as effective as using lights during daylight unless natural daylight is quite bright.

3.2.06 Voltage Regulator

When powering devices that need a reliable constant voltage, a voltage regulator is the way to go. Voltage regulator takes an input voltage and outputs a regulated voltage despite of the input voltage. The output voltage can be fixed or adjustable. In order for these devices to have a fixed or adjustable output a feedback technique is required. These feedback techniques can be as simple as adding a Zener diode and resistors or complex feedback that help with efficiency and improve performance. Voltage regulator can be used to step-up or step-down output voltages.

There are two main voltage regulators: linear regulator and switching regulator. Linear regulators like the LM7805 provides 5 volt and 1 amp at the output with the input voltage ranging from 36 to 7 volts. This device uses a feedback voltage to help regulate the output voltage by adjusting the effective series resistance of the regulator. This method can be called a voltage divider. This method will allow the regulator to output an effective voltage no matter what the current load is on it, but only up to its current capacity.

At 2.0 volts on the standard LM7805 linear voltage regulator, this is the large minimum voltage drop that can occur across the voltage regulator, which is one of the biggest downsides to linear voltage regulators. This results in having to get the stable 5 volts output, at least a 7-volt input is the required. As one can see the voltage drop plays a major role in the power dissipated by the linear regulator, which would have to dissipate at least 2 watts if it was delivering a 1-amp load.

The larger the difference the worse the power dissipation is between the input and output voltage. Due to this difference the regulator would only be 50% efficient. For instance, the 7-volt source regulated to 5 volts delivering 1 amp would dissipate to 2 watts through the linear regulator, a 10-volt source regulated to 5 volts delivering the dame current would dissipate 5 watts. Also, linear voltage regulators can be used to output high current using a BJT or MOFET.

In continuation are the switching regulators. The best solution for low power, low cost application where the voltage difference between the input and output is low and not much power is required is using the linear regulators. The only downside

to the linear regulators is that even though they are very inefficient, which is where the switching regulators come into play.
A switching regulator is the best option only when a high efficiency is needed or a range of input voltage is expected, including inputs voltage below the desired output voltage. Being that linear voltage regulators efficiencies are often that below of 50% the switching voltage regulators have power efficiencies of 85% or better making it the best option given the specific situation.

Due to the efficiency of the switching regulator they generally require extra components over the linear regulator, resulting in the values of the components having much more of an impact on the overall performance of the switching regulators than the linear regulator.

However, in order not to compromise the performance or behavior of the rest of the circuit due to the electronic noise that the regulator can generate one must recognize the design challenges that comes along with using a switching regulator effectively.

Furthermore, there are two different type of voltage regulators, electronic and mechanical. The electronic voltage regulator (EVR) is most common for voltage regulation in many power quality applications. However, mechanical voltage regulators are about 25% cheaper than electronic voltage regulator. Yet the electronic voltage regulator is often used in many applications due the correction in speed than the mechanical voltage regulator. Table 3.9 shows the advantages and disadvantages of the electronic voltage regulator.

Table 3. 9 – Advantages & Disadvantages of Voltage Regulator

Advantages	Disadvantages
Output voltage regulation is good (tap switching) to very good (double conversion)	Poor current overload capacity (except the series transformer design)
Ultrafast voltage correction speed	More expensive than mechanical voltage regulators
No restrictions on the number of correction cycles	
Versatility of kVA rating, voltage and configuration	
Very low or no regular maintenance	

3.2.07 LCD Display

TFT Display

A variant of the liquid crystal display (LCD) is a TFT stands for thin-film-transistor. TFTs can simultaneously retain certain pixels on a screen while addressing other pixels using minimal amounts of energy, which is why TFTs are categorized as active matrix LCDs. In order to remain in operation while still rendering optimal results, the TFTs have to consist of transistors and capacitors that cohesively work to conserve as much energy as possible. Due to the diversity of the TFT display, it allows for the technology to offer multiple features, some are specifically engineered to enhance the overall user experience.

To begin with, mostly used for mobile screens are the bright LED backlights that are featured in TFT displays. The backlight can be adjusted according to the visual preference of the user and offer a great deal of adaptability. Showing how adaptable the TFT can be in some cases certain mobile devices can be set up to automatically adjust the brightness level of the screen depending on the natural or artificial lighting in any given location. This convenience proves to be an efficient feature for those who have difficultly learning how to manually adjust the settings on a device or monitor, so this adaptability makes is easier for sunlight readability

Nokia 5110 Display

The name to this next display sounds familiar due to it was once a popular phone in 1998. The Nokia 5110 mobile phone is being utilized because of its great display features. This Nokia 5110 screen can display alphanumeric characters and bitmap images. Also, it can draw lines and other shapes. The Nokia 5110 display is capable of all these features because of its (84x84) monochrome pixels.

PCD8544 interface IC makes this module easier to use with low-level microcontrollers which is what this module comes with. It does not require more pins because it communicates through SPI protocol. Making this module even more ideal for novice programmers the module also has a readily available library for Arduino.

This display would be the right choice for you if you’re looking for a display that can showcase some decent graphics or custom character and is better than the standard 16*2 LCD.

Any microcontroller that supports SPI communication can also be used with the Arduino and the Nokia 5110 module is commonly used with these. According to the data sheet all the pins are only 3.3V tolerant, hence that the module works on 3.3V. So, depending on the type of micro controller you are using will depend on which logic level shifter to use. For instance, if you’re using a 5V microcontroller which is almost always used, then it is recommended to use a logic shifter like a potential divider to access the SPI pins of the display module.

From the graph above you can find the soldering pad sets on the bottom of the LCD of which we can uses any desired set, as you can see form the graphical LCD. However, there are many duplicates in the market with pads on both sides, but they have the same pinouts and same functionality so there is no need to worry about the difference. All clones have 6 input pins with the same dimensions (1.72' x 1.72')

Dot Matrix Display

To constitute a dot matrix display, the light emitting diodes align in a form. It is commonly used to display temperature, time, news updated and a lot more on digital billboards. When the dot matrix display is manufactured, they are manufactured in various dimensions such as 5x7, 8x9, 128x32, etc. where the numbers represents LED in rows and columns.

The arrangement of the LEDs in the matrix pattern is made in two ways. These two ways are row anode-column cathode or row cathode-column anode. In a row anode-column cathode pattern, the enter row is an anode, while columns serve as a cathode and vice versa pattern is there in the row cathode-column anode. When the power is turned ON the LED wafers that are glued to the bottom of the segments will then glow. Conductor tracks are laid all over the board in order to power each LED, and there are 35 LEDs that are controlled by using a combination of 14 pins.

Standard LCD Display

LCD display are commonly used in various projects. The most common LCD display is the 16X2 which means it can display 16 character for each line and there are 2 lines. These electronic display modules are preferred over multi segment LEDs because they are economical, easy to program, and can display special and custom characters. LCD stands for liquid crystal display. It has two registers which are Command and Data. These registers are used to store the data and instructions. For example, the command register is used to store the instructions given to the LCD and the data register is used to store the data that's going to be display on the LCD. The LCD display is powered by using 5 volts.

3.2.08 Relay

Relays are a vital component for the senor project design as the relays are the switches that open and close circuits electronically or electromechanically. Relays control one electrical circuit by opening and closing contacts in another circuit. For instance, when a relay contact is normally open, there is an open contact when the relay is not energized. When a relay is normally closed, there is a closed contact when the relay is not energized. Regardless applying electrical current to the contacts will change their state as stated above.

Relays can control larger voltages and amperes by having an amplifying effect because a small voltage applied to a relays coils can result in a large voltage being switched by the contacts. However, relays are generally used to switch smaller currents in a control circuit and do not usually control power consuming devices except for small motors and solenoids that draw low amps.

The only thing that can prevent equipment damage are protective relays. They can prevent damage by detecting electrical abnormalities, including overcurrent, undercurrent, overloads and reverse currents. Also, relays are also widely used to switch starting coils, heating elements, pilot lights and audible alarms.

Mechanical Relays

Usually the bulkiest and most jagged of all relays are mechanical relays. For a common mechanical relay, a current goes through a coil magnet to pull a flexible spring-loaded conductive plate from one switch contact to another. Typically, mechanical relays have low speed for switching in the 10ms to 100ms. However, they're usually designed for high currents applications. The current ranges are from 2 amps to 15 amps.

Reed Relays

The reed relay merges a reed switch with a coil into one unit to present as a smaller, higher power-efficient alternative to other types of relays. These units are suitable for automated test equipment, security, medical and process control equipment. They can also be customized.

Solid State Relays

The solid-state relays perform its input to output isolation and switching functions by using the electrical and optical properties of solid-state semiconductors, instead of moving parts like the EVRs. Figure 3.13, pictured below, displays the difference between solid state and electromagnetic relays.

	Solid State Rrelays	Electromechanical Relays
Electrical Noise	• Leverage zero voltage turn-on and zero current turn-offs • Generate minimal electrical disturbance	• Can generate significant signal noise as a result of mechanical system
Electromechanical - Power Consumption	• Feature low power consumption • Require little input power for switching loads • Ideal for creating more sustainable, energy-efficient solutions • High heat generation	• Power consumption is a function of the switching voltage and the internal resistance of the material being used in the switch • Require higher input power to operate
Electromechanical - Shock & Vibration	• Are highly resistant to shock and vibration • Are not susceptible to erratic or unreliable operation in demanding environments	• Mechanical system is subject to external forces that can lead to unreliable and erratic operation
Electromechanical - Switching Capabilities	• Respond to control signals in less than 100μs	• Can respond to control signals in 5 – 15 milliseconds (about 100 times slower than an SSR)
Compatibility with Control Systems	• Do not generate sparks or electric arcs and do not bounce electrically or mechanically • Have isolation levels up to 4kV • Magnetic fields have little effect on them • Are preferable to EMRs in environments where volatile combustibles are in use	• Arc when they interrupt current therefor not suitable for environments with volatile matter • Cannot operate in areas with large electromagnetic forces
Performance in Harsh Environments	• Do not generate sparks or electric arcs and do not bounce electrically or mechanically • Have isolation levels up to 4kV • Magnetic fields have little effect on them • Are preferable to EMRs in environments where volatile combustibles are in use	• Arc when they interrupt current therefor not suitable for environments with volatile matter • Cannot operate in areas with large electromagnetic forces
Positional Sensitivity	• Are positional insensitive • Are suitable for mounting in vertical or horizontal positions, "dead bug" position or adjacent mounting	• Mechanical system is subject to external forces • External force must be perpendicular to relay action

Figure 3. 3 – Solid State vs Electromagnetic Relay

For the Plant Nanny an electromagnetic relay will be used to turn on and off the light for growing plants. However, the plant nanny will be constantly turning on and off the light which might cause the electromagnetic relays some wear and tear. Also, the electromagnetic relay is going to be in an environment that can cause some corrosion and affect its operation. In Table 3.10 shows the advantages and disadvantages of electromagnetic relay.

Table 3. 10 – Advantages & Disadvantages of Electromagnetic Relay

Electromagnetic Relay Advantages	Electromagnetic Relay Disadvantages
Fast operation and fast reset	**High burden level instrument transformer is required**
Use for ac and dc systems for protection of ac and dc equipment's	**The directional feature is absent**
Simple, robust, compact, and most reliable	**Requires periodic maintenance and testing**
Almost Instantons	**Operation can be affected due to aging of the components and dust, pollution resulting in spurious trips**
Possibly can have operating speed in milliseconds	**Operational speed is limited by the mechanical inertia of the component**

3.2.09 Printed Circuit Board

A printed circuit board, or 'PCB' for short, will be used in order to connect multiple electronic devices and sensors together in an organized and elegant manner while maintaining an efficient and small footprint. A PCB electrically connects electronic components using conductive tracks, pads and other features etched from ore or more sheet layers of copper laminated onto sheet layers of a non-conductive substrate [CJ-3]. A soldering tool is used to attach components electrically. The whole purpose of the PCB is so that a circuit can be completely wired together without actually needing physical wires like one would use on a breadboard.

Designing a PCB

Once decided on a project or goal to achieve using electrical resources, you will then begin to pick parts for your design. Make sure to thoroughly test all parts before continuing onto the PCB process. There is potential to fry and ruin a PCB if a miscalculation occurs in the correct voltage or current values.

After testing you then need to decide on a PCB editing software. The software should be a combination of being readily available and user-friendly. Ideally, the software will also come with a wide variety of libraries of components so minimal time is required to track down correct schematics and footprints. Prior circuit design will help immensely in this process. Below is a table (Table 3.11) to compare cost and features of several available PCB editing/modeling software available for the project.

Table 3. 11 – Comparison of PCB Software

Software	Cost	Features
Eagle	Free Students	Many pre-made libraries Autodesk Support Online Community
KiCAD	Free	3D Viewer Open Source Online Tutorials
ExpressPCB	Free	Simple Design & Order Process Open Source Libraries Online Community
EasyEDA	Free	Web-based Tool User-friendly Tutorials available

In the table above it is noted that only free software was considered. While other programs are available with more advanced features, we feel as a group that the extraordinary cost of several of the programs (ranging from $1500 - $5000) to be not worth even considering. The advanced features they offer are, for the most part, out of the scope of our project. We are confident than any of the above software above is more than capable of handling our PCB design requirements.

EAGLE will be the program of choice due to it being easily available to us students. Plenty of YouTube and online communities are available if any problems arise. EAGLE files, can also be easily dropped into fabrication websites such as Oshpark for fabrication.

EAGLE is similar to most other PCB editing and modeling software available out there. The user will choose the size of the PCB by sketching into the layout of the program which creates bounds for the user to then arrange the components as neatly as possible. Most of all the components needed for design can be found in libraries that either come pre-installed with the program or easily downloaded. With EAGLE, a user can even create his or her own library. Within the library a user can create custom schematics and even custom footprints if necessary. This process is a little more advanced and complicated and can form issues not seen prior. For this sake all components needed for our project will come in a pre-created library available for download.

Once the design is finished and the board is as desired and passes all simulation checks, we are done with the software. From here we go on to choose an appropriate fabrication manufacturer company. This company receives our uploaded PCB files and intricately prints out all layers of our PCB circuit board with extreme accuracy. The board is then sent back to us so we can properly and safely solder all components to the board.

PCB Manufacturing

The manufacturing process of a PCB does not come free. As such with all things that have a cost, we will weigh a quality vs time vs cost table to more easily compare and contrast multiple fabrication companies. We also value quality with our PCB board so we will also be researching user related reviews of all companies listed below to get a better understanding. However, these are user experiences that may be biased, subjective, or outright fake. It is important to take internet reviews with a grain of salt and make a non-biased objective decision on a final product. Below is a table (Table 3.12) to compare a list of companies and their prices along with their competitors.

Table 3. 12

Company	Price	Time	Layers	Rating
4PCB	$33	3 Days	2	2.7 10 reviews
OSHPark	$5/sq in.	12 Days	2	4.5 24 reviews
PCBCart	Quoted	Varies	1-8	4.5 6 reviews
PCBWay	Quoted	2-5 Days	1-14	4.0 31 reviews
Seed Studio	Quoted	3-4 Days + Shipping	1-6	3.1 33 reviews

Each company in the table above have the capability of providing more than enough layers for our project design. However, some of the user ratings and reviews raise concerns. OSHPark seems ideal, but the price can vary based on how large the PCB actually is. Assuming our footprint can remain small they may be the ideal choice for our design. If it turns out that the size of our board causes the OSHPark price to go up, then either PCBCart or PCBWay will be consulted to produce our PCB.

3.2.10 Conformal Coating

Due to the environment electrical components are exposed to, conformal coatings are used to protect them. There are many examples of these factors such as salt, dust, moisture, chemicals, mechanical abrasion, and temperature changes. Conformal coating when applied correctly will prevent the board from corrosion. Present day, conformal coatings can also prevent current bleed between closely positioned components and also is being used to reduce the formation of whiskers.

Balance is of allowing oxygen and maintaining protection of the board is key, and conformal coatings allows for both. Conformal coatings are breathable allowing trapped moisture in electronic boards to escape in addition to maintaining protection from contamination. Typically, the conformal coatings are classified in four classes that each of them has their own specific physical and chemical properties and each of them are able to perform different functions. The four classes are as follows: Acrylic, Urethane, Silicone, and Varnish, with these four classes allows for them to be able to perform the following functions:

- Insulation: Allowing closer conductor spacing
- Eliminate the need for complex enclosures
- Minimal effect on component weight
- Completely protect the assembly against chemical and corrosive attack
- Eliminate performance degradation due to environmental hazards
- Minimize environmental stress on a PCB assembly

Ionic substances can be damaging to the precision analog circuitry causing a degraded accuracy if insulating surfaces comes in contact with the substance. Ionic substance such as fingerprint residues, which can become weakly conducive in the presence of moisture. One will have to choose a suitable material coating so that it can reduce the effects of mechanical stress and vibrations on the circuit and its ability to perform in extreme temperatures.

For example, in reference to a chip-on-board assembly process, a silicone die is mounted on the board by a soldering process or adhesive, then electrically connected by wire bonding, with a .001-inch diameter aluminum or gold wire. Because of the delicacy of the chip and wand, they are contained in a version of conformal coating called “glob top”. This is important because it prevents accidental contact from damaging the chip or the wires. A second example for use of the conformal coating is to increase the voltage rating of a dense circuit assembly, this allows for the insulating coating to withstand a much stronger electric field than air at a high altitude.

Most organic coatings are readily penetrated by water molecules with the exception of perylene. In order to preserve the performance of the electronics a coating would be needed, and it would prevent ionizable contaminants such as salts form reaching circuit nodes and combining their water to form a super then electrolyte film. Due to this, coating is far more effective if all the surface contamination is removed first, using a highly repeatable process such as vapor degreasing or semi aqueous washing. Due to the contaminant film making contact with circuit nodes, using pinholes would defeat the purpose of coating, causing it to form undesired conductive paths.

3.2.11 Water Pump

Present day pumps are essential to everyday living. One may not recognize it, but pumps are in refrigerators, cars, cooling computers even heating pools making pumps essential for everyday living even when we don't see the efficiency of having a pump. The most common pumps used in the industry are the centrifugal pumps.

These pumps consist of an induction motor with a shaft that connects to the impeller. The induction motor rotates the shaft in turn rotates the impeller. Changing the speed of the motor will change the speed of the impeller rotation. In this method you can change the flow rate of the system. The impeller is inside of the pump casing which can't be seen.

It has two ports and inlet and outlet; the inlet is always through the center of the impeller and the outlet is usually perpendicular to the inlet. The inlet line is known as the suction line and the outlet line is known as the discharge line. The impeller should always be submerged in water if not it can damage the pump. Around the impeller there is a volute that has an increasing diameter all the way till the outlet. This change in diameter allows more water to flow allowing an increase in the flow rate. The figure below shows a diagram of a centrifugal pump.

Based on their method of operation, pumps are initially distinguished into types. One primary pumping mechanism is kinetic (dynamic) which are centrifugal pumps and the specialty pumps. These pumping mechanism pump power and move water through the system using the fluid velocity and the resulting momentum. The other primary pumping mechanism is positive displacement pump which are reciprocating pumps and rotary pumps. Positive displacement pumps include all pumps which use fixed volume cavities displaced using a mechanical force to move fluid through the system. These pumps differ based on whether the motion used to displace the chamber is reciprocating or rotary.

Displacement pumps are used to force the water to move by displacement. This means pumps such as diaphragm pumps, piston pumps, roller-tubes, and rotary pumps. The old-fashioned hand-pumps as well as the grasshopper like oil well pumps, the ones you operate by moving a long lever handle up and down, are piston displacement pumps. Displacement pumps are used for moving very thick liquids, creating very high pressures or creating very precise flow volumes. In addition to oil wells they are also used for fertilizer injectors, spray pumps, air compressors, and hydraulic systems for machinery. However, you will not see them typically used for irrigation systems, with the exception of fertilizer injectors (used for mixing fertilizer into irrigation water).

The most common type of centrifugal pump is the "End-Suction Centrifugal pumps". To make it a single unit, typically the pump is "close-coupled" to an electric motor, that is, the pump is connected directly onto motor's drive shaft and the pump case is bolted to the motor. The water enters the pump casing through a "suction inlet "centered on one side of the pump, and then exits at the top of the pump casing. End-suction centrifugal pumps generally need to be primed the first time they are used, after that most will not require priming. If the pump needs to be primed each time it is turned on this almost always means, there is a tiny leak in the intake pipe. Almost all portable pumps are end-suction centrifugal type pumps.

End-Suction Centrifugal pumps are a great use as irrigation booster pumps however, they are designed to push water, not pull it. They are very good for pumping water from any source where the pump is installed level with, or below, the water level. However, the pumps perform less efficient, any time they need to draw the water up from a water source below the pump. Therefore end-suction centrifugal pumps are not the best choice for pumping water from a water source that is more than a few feet lower than the pump. When sucking water up into the pump they must be installed as close to the water surface level as possible, which is often inconvenient, especially for locations where the water level may go up and down, like some lakes, rivers, creeks and ponds. Each pump is different, so check with the manufacturer to determine the maximum height the pump can be installed above the water surface. Typically, the general guideline will be a maximum of four feet above the water surface. But keep in mind, the higher the pump is above the water surface, the less efficient that pump is going to be.

Submersible pumps are typically centrifugal type pumps that are installed completely underwater, often including the motor. (Not all submerged pumps are centrifugal types, but the term "submersible pump" is almost always a reference to a submersible centrifugal pump.) A centrifugal submersible pump consists of a water-proofed electric motor and a pump combined in a single unit. So that it can fit down inside of a water well, it's has a larger size submersible pump and motor will be shaped like a long narrow cylinder. Smaller size submersibles are often designed to sit on the bottom of a pond, tank, or sump and are often used as fountain pumps or sump pumps. As long as the water is deep enough, submersible pumps can also be placed in a stream or lake, even though the majority of the submersible pumps are actually designed to be installed in a well.

Depending on the pump, some can also be installed sideways in shallow water as well, although this is not common, some pumps can be installed this way, just be sure to check the instructions. A common submersible pump installation method for lakes and rivers is to mount the submersible pump underwater in a "sleeve" made of well casing pipe that is attached underwater to the side of a pier piling or a post. Some are attached to the bottom of a float or floating dock.

Unlike centrifugal pumps, submersible pumps don't need to be primed since they are already under water. They also have higher energy efficiency because they only push the water, they don't need to suck water into them. Most submersible pumps must be installed in a special sleeve if they are not installed in a well (with large diameter wells they sometimes need a sleeve even when installed in a well.) The way the sleeve works is, the sleeve forces water coming into the pump to flow over the surface of the pump motor to keep the motor cool. The sleeve is essential because without a sleeve the pump may over-heat. Due to the placement of the pump, because the power cord runs down to the pump through the water it is very important that it be protected from accidental damage. This would prevent the boat getting tangled up in it, or a snapping turtle or alligator trying to bite through it.

Many submersible pumps are actually several smaller centrifugal pumps stacked on top of each other to create higher flow, more water pressure, or a combination of both. This is why they are often time considered "multi-stage" pumps.

A turbine pump is a centrifugal type pump mounted underwater and attached by a driveshaft to a motor mounted above the water. In reference to energy efficiency, turbine pumps are comparable to submersible pumps. Turbine pumps are used primarily for larger pump applications where the size of the motor would be difficult to fit in a submersible structure. Often turbine pumps consist of multiple stages, each stage is essentially another pump stacked on top of the one below. For example, it works like a train with multiple engines hitched together pulling it, each stage would be an engine.

Turbine pumps are typically the type of pumps you see on farms or municipal water district wells. You are able to identify a turbine pump, when you see a huge motor mounted on its end and a pipe coming out sideways below the motor, that is most likely the motor for a turbine pump located down below it in the well or an underground tank. Turbine pumps can also be used for in landscaping. A typical landscape use for a turbine pump would be in a large park or golf course where water is coming from lakes. The turbine pump is mounted in a large concrete vault with a pipe connecting the vault to the lake. To being with the way it works is the water flows by gravity from the lake through the pipe and into the vault. Secondly, from there a turbine pump sends the water under pressure through pipes to the irrigation system. And lastly, two or three different sized turbine pumps are often placed side-by-side to handle different flow combinations.

A jet pump is a hybrid version of a centrifugal pump merged with a jet device. The jet device greatly improves the pump's ability to lift water from a water level that is significantly below the pump. Unlike centrifugal pumps which have difficulty sucking water up into to the pump, the jet pump does not have this difficulty. The "trade-off" here is that while jet pumps are great at sucking water, they tend to have lower flow capacities than what is optimal for most sprinkler systems. But there are some situations where they are just what you need, and they are common in areas with shallow groundwater like Florida.

An example usage would be pumping from a pond or river where the water level varies, and the pump needs to be installed above the high-water line. Another use is for pumping from a shallow "sand point" well like those commonly used in Florida. As mentioned above, one must consider when the using a jet pump it is going to have a lower flow rate than a standard centrifugal pump of the same horsepower.[38]

As you can see each pump has a specific design, that is designed for the work that it will complete as well as the placement of the pump. Different pumps various in sizes depending on where the location of the pump will be to ensure its efficiency and less likelihood of getting damage. As well as each pumps horsepower, and sucking force to make it effective. Whether a centrifugal, submersible, turbine, or jet pump each pump is essential in the getting the water to flow throughout.

3.2.12 Multiple Pumps VS Valve Design

In order to regulate the fluid flow in which regulates the pressure drop in a flow line you would need a value. Valves are essential in the common final control element in order for a process control system to maintain pressure, composition, temperature, or other process quantities. For instance, some valves are more essential in applications in which the valve is mostly for starting and stopping the flow of a pipeline. Which is why there are many types of values with different weaknesses and strengths depending on what application the value is needed for. There are many different types of valves, for example a ball valve or gate valve may be uses for a design that has low pressure drop. Another example is a globe valve, it is a valve that would be better used for maintaining a specific flow rate into a process.

As you can see each valve is a vital component depending on the specific job that is needed to be completed.

Each C_V valve that has different suppliers and body sizes has a different value. In addition, the C_V is a measure of the size of a value. In order to regulate the flow through the valve you have to adjust the valve position or lift L. Depending on the type of trim installed, that's what would determine the lift function F(L). Unlike the trim, which is must easier to modify, in order to adjust the size of the C_V you would have to replace the valve body. A function of flow q can be determined by rearranging to solve if P_V as if would give the pressure drop across the valve.

The process for designing a particular valve, is by maintaining a linear relationship between lift *l* and flow *q*. In order to compensate for the nonlinearity, due to the nonlinear relationship making the flow control tuning more complicated, it requires gain scheduling, specific linearization in the control software, and other measures to compensate. The most popular valve such as equal percentage valves are popular valve trims to compensate for typical process nonlinearity and create a combined valve plus system response that is linear.

To lock in on a command valve opening, valve positioners measure the valve travel and automatically adjust the actuator to precisely lock. In order to precisely have a valve follow a command a valve positioner will improve the process. By being an inner feedback loop, it allows the valve to match a valve opening set point.

In order to determine the particular lift function *f*(*l*), you have to select the valve design which involves selecting the type of valve, the trim and the body size C_V. However, there are a few important concepts that are important in the valve design itself, specifically three. First, the sum of the pressure drop across the valve and system is equal to the pressure generated by a pump.

Pressure is generated by pumps and dilutes over vales and the system.

$$\Delta P_{pump}=\Delta P_V+\Delta P_{system}$$

Some of the systems have a quadratic relationship between flow and pressure drop.

$$\Delta P_{system} \propto q^2$$

The total pressure drop at typical operating condition should be 1/3 to ¼ of the pressure drop across the valve. Low pressure drop means the valve is oversized, the valve is too large for that application, and may have a hard time with fine-tuned flow adjustments. High pressure drop means too much pumping is being consumed by the valve. To avoid the parasitic valve pressure-drop, use pumps with variable frequency drives to help regulate the flow.

Using multiple pumps allow a more efficient way to pump water at variable flow rates or variable pressures. Pumps can either be used in series or parallel. Pumps in parallel yields extra flow while pumps in series yields extra head. One way to increase the volume of the water pumped is to have the pumps in parallel. Also, adding another pump it can be easily inserted into the line if more flow is required.

Valves are not recommended to control multiple pumps in parallel because it reduces the flow. Lowering the flow causes each pump to oppose the others back pressure. However, using a valve for each pump instead of one valve system, can help deliver the pressure and the flow if necessary.

3.3 Strategic Component & Part Selection

This section will focus on the specific components that we feel our ideal for our design. These parts were found doing extensive research on quality vs cost analysis. For each part, several comparisons will be made between multiple similar products so that we can further show the decision-making process on why certain components were chose over others. Any advantages and disadvantages we discovered during research will be talked about in moderate detail.

3.3.01 Microcontroller

MSP430FR6989

The MSP430FR6989 is a RISC based microcontroller developed by TI (Texas instruments). It is an ultra-low powered platform that features 7 different low power modes for optimized energy consumption. The MSP430FR6989 has 128 KB of nonvolatile memory as well as 2 KB of RAM providing just enough memory space to store all code for the project. The microcontroller communicates with its peripherals using UART, mSPI, and I2C communication standards. It has 83 GPIO pins, meaning that there are more than enough I/O pins to integrate all the parts for the system. It is however the most expensive of the microcontrollers that we are considering with pricing at $9.64.

ATmega328P

The ATmega328P is a microcontroller commonly used in Arduino products such as the Arduino Uno and Arduino nano. It is a high performance and low power 8-bit AVR microcontroller that uses a RISC based architecture. The ATmega328p microcontroller usually uses the Arduino IDE, an easy to use and popular option for IoT devices. The ATmega328p has 23 GPIO pins so it has enough to handle input from the rest of the system. It communicates with the peripherals using SPI, UART and I2C communication protocols and has a clock frequency of 20 MHZ. With a power consumption of 1.5 mA at 3V and the ability to go into low power mode, it has a very low power consumption compared to other microcontrollers. With 32 KB of nonvolatile memory space and 2 KB of RAM, this microcontroller has enough space to store preprogrammed functions for the system. At only $2.18, the ATmega328p is the cheapest of the 3 microcontroller options for our project.

ESP8266

The ESP8266 is a System on Chip (SoC) manufactured by Espressif, a Chinese company based in Shanghai, China. It consists of a Tensilica L106 32-bit micro controller unit (MCU) and a Wi-Fi transceiver. It has 11 GPIO pins (General Purpose Input/output pins), and an analog input as well. This means that you can program it like any normal Arduino or other microcontroller. It has a clock with a frequency of 80 MHz that can be increased. For communicating with peripheral, the ESP8266 supports I2C, UART, I2S, and SPI communication standards. With 11 GPIO pins available for use, there is enough pins for all the input and output for our project. It has a user memory space of 40 KB of RAM; it uses an external flash memory that usually range from 512 KB to 1 MB depending on the board. This means there is more than enough to save necessary functions. A table of comparisons of specifications of the different microcontrollers is shown below in Table 3.13.

Table 3. 13 – MCU Comparisons

	MSP430FR6989	**ATmega328P**	**ESP8266**
Clock rate	16 MHz	20 MHz	80 MHz
RAM Memory size	2 KB	2 KB	30 KB
Nonvolatile memory size	128 KB	32 KB	-
Number of GPIO pins	83	23	11
Communication methods	SPI, I2C, UART	SPI, I2C, UART	SPI, I2C, I2S, UART
Price	$9.64	$2.18	< $4

For our project we use the ESP8266 microcontroller. This is because it satisfies the needs of our project with adequate memory space and clock speed and GPIO pins, allowing for our project to function without issue. It is also readily available to us for use due to the donation of one of our group members, this saved our group some money for other parts that we needed.

3.3.02 Wireless Communication Module

For our project we use the wireless communication technology that is wi-fi. This is because compared to other technologies that we come across during our research, wi-fi provides our system high speed communication. Unlike other technologies, it is possible for users to stay connected with their system anywhere in the world through wi-fi by connecting to the internet.
We have chosen to use the ESP8266 Wi-Fi module for our system to communicate wirelessly with the user. The ESP8266 is a System on Chip (SoC) with that can provide wi-fi capability to a microcontroller and is manufactured by a Chinese company named Espressif Systems. It has become one of the most popular IoT (Internet of Things) device and an image of the module can be seen below in Figure 3.14.

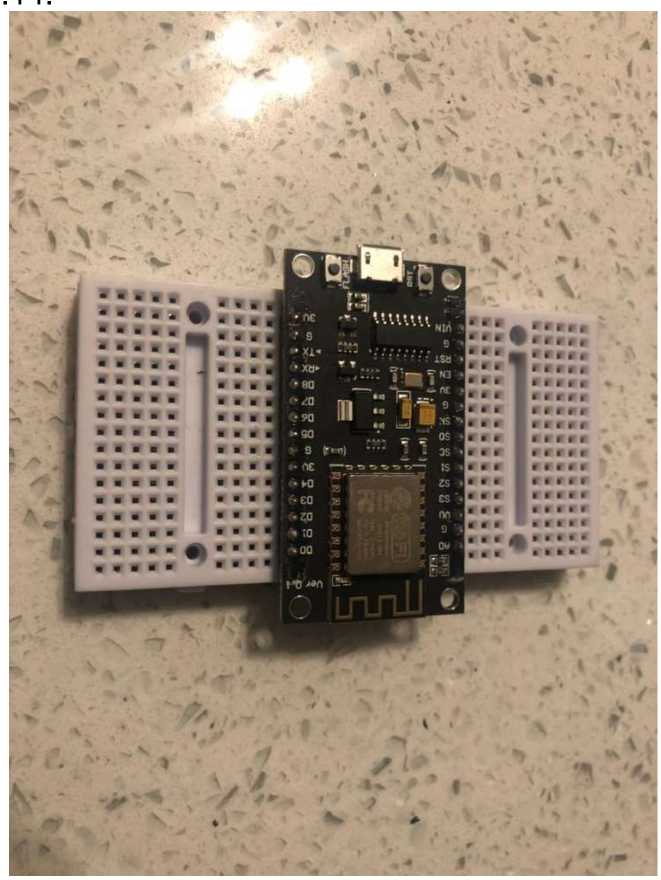


Figure 3. 4 – ESP8266 Module

The advantage we have for using the ESP8266 as our wi-fi communication module is that the ESP8266 can also function as a microcontroller. Since we chose it as the microcontroller to run our system, we can save money by not having to buy an extra wi-fi module because it has inbuilt wi-fi support. All the advantages that we mentioned in the section above describing our choice for the microcontroller part and why is valid and can be used here as well.

3.3.03 Water Pump

In order to select the most suitable pump for our design we first had to set some standards the pumps need to have. First, the water pumps dimensions cannot be too large because it requires to be inside of the housing of the Plant Nanny. Second, it must be able to pump and discharge enough water in a short period of time for our design to be efficient. Third, the water pumps need to have a low power consumption for the design to not dissipate large amounts of heat. Lastly, since three water pumps are needed for this design, the cost for the pumps should be inexpensive.

Most of the mini water pumps operate 3 to 12 input volts. However due to using a power outlet for the power supply, the amount of voltage needed is not an important factor. The most important factor will have to be the size of the pump. This is crucial for the spacing of the Plant Nanny because the PCB with all the other components and the wiring must fit inside of the enclosure.

The Brushless Submersible water pump from amazon has the best size for this project design. The pump dimensions are 2X2X2.4 inches and it is small enough not to affect the spacing of the enclosure. Also, it pumps a large amount of water for its size. The brushless submersible water pump can discharge water at a rate of 7.5 liters per minute, while the other water pumps like the Sukragraha water pump only discharge 1.6 liters per minute. However, the Sukragraha water pump does have a lower power consumption than the Brushless Submersible water pump. Below in Table 3.14 you will find a comparison of water pumps. However, due the voltage regulator switcher we went with the Gikfun water pump because it’s power by 3-5 volts

Table 3. 14 - Water Pump Comparison

Pump	Voltage	Cost	Size	L/Min	Power Consumption
Northbear Micro Submersible	12V DC	12.99	6 x 3.7 x 0.4 inches	14	15W
Sukragraha Micro Submersible Motor water pump	3-5V DC	5.99	5.5 x 3.4 x 1 inches	1.6	1W
Bringsmart JT - DC3L Upright Water Pump	4.5V DC	8.99	5.3 x 3.3 x 1.9 inches	1.7	0.91W
Brushless Submersible Water Pump	12V DC	11.99	2 x 2 x 2.4 inches	7.5	6W
Gikfun Micro Submersible Water Pump	3-4.5V DC	11.98/4	5 X 3 X 0.9 inches	1.7	0.9W

3.3.04 Sensors

Water Level

For our project we decided to detect the water level through the usage of the HC SR04 ultrasonic water level sensor. this sensor will track the water level in the reservoir at different locations, we can keep track of the level of the water within the reservoir. The project places probes at locations marked 100%, 50%, 25%, and 0% as illustrated in Figure 3.15 below.

Figure 3. 5 – Water Level Sensor Demonstration

Since the the sensor will not come in contact with water, we do not have to worry about ensuring they do not get corroded.

Moisture sensor

we decided that the best type of moisture sensor that can be used for the project is a cheap resistive soil moisture sensor. This is because other moisture sensors are more expensive than any regular resistive moisture sensor that can be found online. Another great advantage of it being so cheap and common is that it can be easily replaced if the sensor gets corroded orr stops working

Temperature Sensor

There are many different temperature sensors that we could use for our project, but we have decided to go with a digital temperature sensor. digital temperature sensors are analog devices that can detect the current temperature of the environment and send the data as a digital signal to the microcontroller. These sensors use I2C and SPI communication protocols to send the information which is good for our project because our microcontroller will be able to support those communication standards.

The specific digital temperature sensor that we have decided to use for our project is called the DHT11. Adafruit.com describes these sensors as “very basic and slow but are great for hobbyists who want to do some basic data logging. The DHT sensors are made of two parts, a capacitive humidity sensor and a thermistor. There is also a very basic chip inside that does some analog to digital conversion and spits out a digital signal with the temperature and humidity”. The DHT11 is very low cost and has a price of range between $1 to $2 depending on the seller, some e-stores even sell it for less than $1. This temperature sensing device uses an operating voltage of 3V to 5V for the power and I/O. this is a very small sensor with the dimensions of 15.5 mm x 12 mm x 5.5 mm and can be easily fit into our system. It has 4 pins and but only 3 of them are used for project as you can see in Figure 3.17, this is because the 3Pin is the NULL pin and is usually not used.

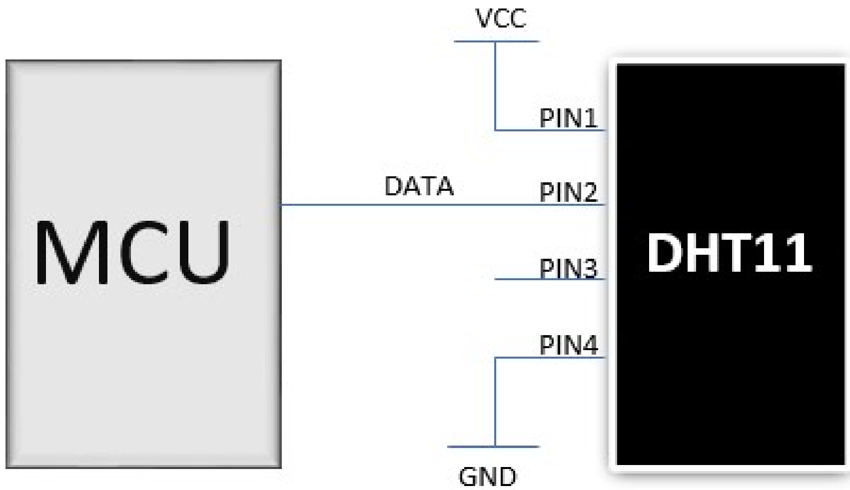


Figure 3. 6 – DHT 11 Pin Layout

The DHT11 is able to sense temperature accurately within the range of 0 – 50 °C (32 – 122 °F). The DHT11 temperature sensor readings have a 5% accuracy, but for the purposes of our project this range in error is acceptable. The DHT11 temperature sensor also has a sampling rate of 1 Hz (once every second) which is usually a bit too slow but since our plant growth system that will be placed indoors, we can assume that temperatures will not change drastically. Therefore, this sampling rate is more than acceptable for the project.

Light Sensor

Of the many different types of light intensity sensors, we decided to go with a light dependent resistor (LDR) sensor for our project. This type of sensor technology works by sensing the intensity of light in the environment, it will then output an analog voltage that varies in proportion to the light intensity. That means the greater the intensity of the light, the greater the voltage sent out by the LDR sensor. Our systems microcontroller will receive this voltage and convert it into a value that can be used.to determine whether or not the system need to increase or decrease the intensity of the light shining onto the plant. Plants will use this light for the process of photosynthesis where it will break down water and nutrients in the soil with the help of sunlight to create ‘food’ for the plant.

For our project we have decided to use the BH1750 analog light sensor in order to measure the intensity of the light for the plant. This sensor has an operation voltage of 2.5V to 5.5V and is a very small sensor that can be conveniently fit anywhere in the project.

Humidity sensor

For our project we decided to also use the DHT11 as our humidity sensor. The humidity sensor is helpful to our project because when the humidity in the air is high, the plants cannot make the water evaporate leading the plant to eventually rot. We can detect the humidity in the plants surround to prevent this from happening. The DHT11 temperature and humidity sensor can help detect the humidity level in the environment in the range of 20 to 90%. The humidity sensor has an error range of 5%. Although it is unlikely to encounter this problem as our plant growth system is for indoor plants, we can still take measures to ensure maximum plant care.

3.3.04 LCD Display

Another important feature of our Plant Nanny is the display interface. The display will show the readings of the plant's moisture level, PH level, light intensity level, the last time it was watered. The display will also show the user how much water is left in the reservoir and when the reservoir needs to be refilled. One of our goals is to create a touchscreen interface that will give the user the accessibility to water the plant from the touchscreen. Also, program a watering schedule for the plant and turn on and off the light from the display. For right now we are just focusing on getting the display to read results however having a touchscreen interface for the user is not out of the question.

In creating this project, we will like to have a device that's economical because we are college students and our finances are working against us. So, choosing the perfect screen for the right price will drive us closer to our goal of creating a user-friendly Plant Nanny. The cheapest display that will get the job done will be the 16X2 standard LCD display. The 16X2 standard LCD display cost $3.95. It has the lowest resolution from the table below. However, it will show the readings from the Plant Nanny and have special characters if need. The only problem is the technology is outdated and it's not touchscreen.

The next possible display for the Plant Nanny will be the Nokia 5110 display. This display can show all the readings from the Plant Nanny and display certain images. The Nokia 5110 display has a better resolution level than the 16X2 stand LCD display, but the display is smaller. In addition, it does not come with a touchscreen interface.

Following the Nokia 5110 display is the white OLED display. This display is more vivid than the Nokia 5110 display, with its higher resolution, it gives the user a better visual experience. But due to the size of the screen at 0.96 inches diagonally it's not making the cut to be the display for the Plant Nanny.

Last but not least the TFT touchscreen LCD display. This display meets all the display requirements for the Plant Nanny. It has great resolution at 128X160 color pixels. The operating voltage of 3.3 to 5 Volts and it has an economical cost of $11.39. However out of all the display in the table below, it is the most expensive. TFT touchscreen display is perfect for creating a touchscreen interface where the user can interact with the Plant Nanny. Below in Table 3.15 you will find a comparison of different displays. However, no display was used due to the time constraint.

Table 3. 15 – Comparison of different displays

Display	Operating Voltage	Operating Current	Resolution	Size	Price
Nokia 5110 Graphic LCD	2.7 - 3.3V	50mA max	84X48 Pixels	1.5 inches diagonally	$4.95
16X2 Standard LCD	4.7 - 5.3V	2.5mA max	32X40 Pixels	64.5mm x 16mm	$3.95
White OLED	3.3 - 5V	20mA max	128X64 Pixels	0.96 inches diagonally	$5.95
TFT Touchscreen LCD	3.3 - 5V	50mA	128X160 color Pixels	3.5 inches diagonally	$11.39

3.3.06 Plant Lighting

The plant lighting involved multiple options at different price points, but it came down to two different light fixtures based on the circumstances presented. Both would supply the ability to have a variable amount of light over the plants, and the proper colors of the light spectrum to provide the correct nutrients for whatever plant is chosen. The two models being heavily compared are the AquaIllumination SOL LED Lighting and the AOVOK Grow Lamp Plant Light Panel.

Although the SOL is meant to be an aquarium light it still covers the full color spectrum required for a plant to grow, and it supplies a variety of lighting options that would lead to more customizability for a client. This lighting fixture is high quality and offers many options for anything a plant can require when it comes to light. The price point is a lot higher when it comes to lighting and nears close to two hundred dollars. This was considered an option because of a free offer from a secondary source on top of its large amount of customizable options.

The AOVOK offers a plant light fixture with the full light color spectrum and can be essentially used for any size plant. The AOVOK uses little power in comparison and costs only a fraction of the cost of the SOL. The AOVOK provides an all-around good lighting fixture for the plants that provides flexibility and versatility of how it can be placed and what types of plants it can cater to.
Both offer everything a plant could need, and that other details to decide the light fixture to be used. The SOL uses almost twice the power of the AOVOK at seventy-five watts, but there are other factors that help the SOL compete. When it comes down to the wire the newer technology will prevail for its versatility with the everchanging devices of the modern world. However, due to the large size of the AquaIllumination SOL LED lighting we had to replace it with the Boosted Grow Plant Light panel.

3.3.07 Voltage Regulator

There are many manufactures that produces voltage regulators. Companies like Texas instruments, STMicroelectronics, Diodes Inc, Microchip, and Richtek USA Inc are the most popular vendors for voltage regulators. In order to find a voltage regulator that is suitable for the Plant Nanny, certain factors should be considered. For example, their maximum input voltages, maximum input currents, temperature ratings, and the difference between input and output voltages. For the Plant Nanny we need three different voltage regulators. Each of these voltage regulators need to output three different voltages: 12 volts, 5 volts, and 3.3 volts. In addition, each voltage regulator should output three different currents: 3A, 502.5mA, and 40mA.

After researching which voltage regulator to choose for the Plant Nanny, we came across TI web bench. TI web bench takes in the parameter needed like input and output voltage and current ratings and will show you the voltage regulators for the solution. Since we are dealing with devices that operate in specific parameters, choosing a voltage regulator using the TI Web Bench will be most efficient. The TI Web Bench voltage regulator we choose is the TPS74101. This voltage regulator outputs 5 volts at 40mA. For the other two voltages and currents we chose TI's Switcher converter also known as a DC/DC Buck converter.

3.4 Part Selection Summary

The parts chosen for this project were carefully selected to ensure satisfaction of the requirements to keep a plant alive as well as to minimize the maintenance a client would have to perform. From the lighting to the LCD display and the sensors certain characteristics were kept in mind when choosing these parts. The power draw that would be required, the ease of use, the reliability of these parts, the cost, and the accuracy. All parts come together to form an easy to use and reliable set up that a plant owner can trustingly use to provide accurate feedback of their plant's health.

The power draw is an important factor to make sure that the cost of running this project doesn't outweigh the practical use a client can get out of this. Ease of use should always be a priority because it can keep tasks from becoming too complicated. Reliability of parts can mean the difference between maintenance once a week or maintenance once a month. To have reliable parts can be a relief because it's less work to keep something complex together in one piece.

Cost can come into a factor including when it comes to quality of parts. The most expensive part could be close to one thousand dollars while the cheapest part could be less than a dollar. The hard part is finding a part that doesn't fall out of budget but is still reliable and practical for what it's needed for. The cost can make or break the differences between two parts to keep the project within the budget. Accuracy is one other aspect that remains extremely important, the sensors need to give correct information to a specified degree. If the parts aren't accurate than the plant isn't fully safe in its environment, and it could be too cold or have too much water. This would be catastrophic for the project because it would be doing the opposite of what a client would purchase this for.

4. Standards

To have a successful project that is built properly and safely will require a set of standards to work from. This set of standards are meant to be industry standards that both keep users safe as well as make sure the project is developed smoothly. Standards are meant to keep a project in compliance with requirements such as size, power consumption, regulations, and economic limits. This team has the requirement to observe and uphold these standards to further create this project.

This section primarily covers:

- Wireless Technology Standards
- Sensors Standards

- Hardware Testing Standards
- C Coding Standards
- Soldering Standards
- International Software Testing Standards

4.1.01 Wireless Technology Standards

Table 4.1 displays all the IEEE standards for wireless connectivity. It shows the different transfer values as well as ranges for ISM bands. It covers all 802.11 standards related to the project.

Table 4. 1 – Wireless Technology Standards

IEEE Standards	Descriptions of Standards
IEEE 802.11a	Wireless LANs that operate a data rate up to 54 Mbps in the 5 GHz ISM band.
IEEE 802.11b	Wireless LANs that operate a data rate up to 11 Mbps in the 2.4 GHz ISM band.
IEEE 802.11g	Wireless LANs that operate a data rate up to 54 Mbps in the 2.4 GHz ISM band.
IEEE 802.11n	Wireless LANs that operate a data rate up to 600 Mbps in the 2.4 GHz and 5 GHz ISM bands.
IEEE 802.11ac	Wireless LANs that operate a data rate up to 1 Gbps for multi station use and 500 Mbps on a single link with below 6 GHz ISM bands.

4.1.02 Sensor Standards

The IEEE sensor standard of how parameters are defined. Table 4.2 below displays the standard

Table 4. 2 – Wireless Standards

IEEE Standards	Descriptions of Standards

IEEE 2700	The standard for performance of sensor parameter definitions

4.1.03 Hardware Testing Standards

Testing hardware has no specific standards when it comes to engineering, but development still involves a process that requires specifications towards deciding whether a part of a project performs to expectations. The tests that this hardware can undergo includes functionality testing, unit testing, and integration testing.

Testing can involve numerous ways of looking at the full scope of a project, and functionality testing does that. Through functionality testing the basis of what is required is put into perspective and observed further. A piece of hardware can be tested to make sure it performs the correct job, and that this job is done within a certain error margin when in cooperation with software. These tests should be somewhat rigorous to be able to see the full extent of what the hardware is capable of handling.

Unit testing should be a programming performance observation that entails the project can perform in every way it's expected to work. The premise of this begins with the basis of programming of the low-level language utilized. The software should return correct and accurate values to the user, and if these variables don't perform to standards than the software and hardware should be both checked and calibrated. All unit tests are meant to be individual tests for each part of the project to make sure that everything is not only completely operational, but also can handle most stress tests thrown at them.

Integration testing is meant to be the pinnacle of this project's evaluation. It is meant to analyze how each individual part and piece of code coincides with one another, and this also involves making sure that everything meshes together into one large piece of software or hardware. It's not only enough for one piece of hardware to be able to interact with another, but everything must correspond and cooperate with the other pieces. How thorough this test is applied can be crucial to having all the parts of this project working in the end. If this test continues to fail, then the project will never be complete no matter how many parts are working in the end.

4.1.04 C Coding Standards

Through the process of programming certain standards should be in place to ensure a working and organized product. Designing software should be done as meticulously as hardware is done, and everything should be well documented to fall back to where a certain problem might have occurred. How certain parts are organized can make a difference in readability, efficiency, and usability. When programming certain aspects should be standard such as commenting, coding style, headers, and formatting code.

Commenting:
One of the most important aspects of any program due to its helpful nature. Allows future programmers to quickly adapt and figure out the function of a certain program.

- Applied and configured with the use of a // or /*…*/ depending on the situation.
    - The double slash is meant to be used for commenting a single line with information.
    - The other use of slashes and asterisks is associated with multiline commenting to leave large blocks of explanation.
- Different types of unspecified coding types will be found within each program, and this are objectives that can be deciphered by looking at placement.
    - Block comments will be found with multiline use at the top of large segments of code to explain initial functionality.
    - Commenting single lines of code will usually be found right above whatever line of code it's describing.
    - Code documenting a certain program will be found towards the top of said program describing its overall functionality and any other designating features.

Coding Style:
This portion is mainly to help readability as well as keeping the program organized and appealing to the eye, but it also helps the flow of the program.

- Order import statements appropriately for organization purposes.
- Acronyms should be used as words.
- Variables should have appropriate names to their corresponding function.
- Functions should be used as tools and not as main portions of programming.

Program Headers:

Program files should have a basic format at the start of every readable program. The main header should have distinguishing information with specifics and dating.

- The document should have a description into what that specific file accomplishes for the software and how it's meant to successfully complete this.
- The other portion should involve a type of timestamping referred to by its month, day, and year of creation.

Code Formatting:
The organized part of code creation that involves coding practices which don't affect the program in any means. They are meant for aesthetic and organizational purposes only. These are common programming standards in how everything should be formatted.

- The basic spacing to be used on each new line will be tabs and will be consistent throughout the program for all types of indentation.
- Lines should not pass the designated margin for the given programming IDE. This usually alludes to be less than 80 characters in length per line, but that limit is also based on indentation.
- A brace at the start of a function, program, or statement should be placed at the end of the same line as the declaration.
- A brace at the end of a function, program, or statement should be placed on the line after the last word to be typed.
- Variable declarations should always be placed at the top of a function or program whether they're global or function based.
- A multiline expression or statement should be broken up properly instead of being forced into one single line.
    - High-level breaks will be used instead of lower level ones.
    - New lines will be placed at the same indentation as the line above it.
    - A statement or expression should be broken up at ideal parts of it such as at a comma or another operator.
- A single blank new line should be used in certain circumstances to separate distinguishing parts of a program.
    - Use these to separate functions from each other as well as statements.
    - It should be used to separate the start of a function from the first variables declared.
    - For commenting a line should be placed before and after a single or multiline comment.
    - A line should be placed before any block of code.

4.1.05 Soldering Standards

Soldering is an important when designing hardware, and it keeps the project together as well as the connections intact. How you operate a soldering iron, and what materials you use can make all the difference in how clean and safe the experience can be. The process of soldering presents itself as a pinnacle portion of the hardware development that should not be taken lightly. When handling the soldering iron safety should be the number one priority. Safety standards included in Stony Brook University's paper called "Soldering Safety" includes a premise towards the ideal work area for something that is considered safe to solder a printed circuit board on. **[30]**

- Soldering irons should never have the tip touched due to the heat that can reach close to 400 degrees Celsius.
- Wires should be handled with tweezers or clips. This not only helps to steady a wire for soldering, but it also keeps the user safe from accidental burns.
- A cleaning sponge should always be wet and in use with a soldering iron.
- Soldering irons should be returned to a stand when not in use to keep track of where they are always, and the soldering iron should never be placed on a workbench.
- When a soldering iron is not in use it should be unplugged and out of the way when working with various parts.
- Eye protection should always be used when a soldering iron is both on and or still hot. Solder can "spit" which always has a probability of getting into your eyes unless protection is used.
- Using lead free solder is important because the lead can be carcinogenic and toxic when burned.
- Cleaning solvents should be kept in dispensing bottles to reduce the risk of inhalation hazards that can be bad for humans.
- Washing your hands with soap and water after handling solder.

Another important aspect is keeping the soldering station in use organized and clean. This allows the user to make less mistakes along the way due to confusion or accidental soldering. The aspects of a clean organized station can range from proper solder use to how to clean your soldering equipment. The document that was followed for reference was written by NASA and it's their paper titled "Soldered Electrical Connections: NASA Technical Standards". Parts of this article were followed directly such as: **[31]**

- A clean workstation as well as clean tools should be consistent to get the best use out of the tools and environment.
- Parts are to be surface mounted for reliability of soldering connections.
- The soldering points will be made in clearly marked positions designated by the manufacturer. This should allow the parts to be placed in their proper order and will not short the board due to wrong connections that are made.

- Parts are meant to be mounted in parallel to the surface mount shown on the printed circuit board. This ensures that connections are proper and not in a series that could harm the integrity of the board or cause a part to malfunction.
- All parts should be secured in place either by clamps or other means to reduce the amount of movement. A minimal amount of movement ensures that parts can be soldered on properly from the start. Soldering on a component improperly could lead to a short on the printed circuit board.
- Soldering points are to be cooled to room temperature over time without any type of other coolant besides open air. The use of tools could cause the solder to come off or burn a person.
- Solder should cover all parts of the conductor on the printed circuit board including the termination area. Adding to much solder to the equation could cause the circuit to short out that area of the printed circuit board. This could also short out any pins involved on the soldering point.
- Solder should be cleaned off of all solder residue with a solvent approximately thirty minutes from when it is applied. This allows for connections between terminal and pins to have a better application.
- A new printed circuit board will have to be obtained if a connection is damaged or a pattern is broken. This can be done through the manufacturer.

4.1.06 International Software Testing Standards

Table 4.3 below shows a figure of all the standards that are used for international testing standards. It goes over briefly what every individual standard is for and a small application of how it is used. This includes both IEEE, ISO, and IEC standards that cover all applications of international software testing.

Table 4. 3 – International Software Testing

IEEE Standards	Descriptions of Standards
ISO/IEC 25000:2005	For software quality requirements, this is currently known as SQuaRE. It’s meant to organize and provide a way to evaluate requirements and specifications.
ISO/IEC/IEEE 29119-2	For software testing this standard will cover processes and aims to have a generic model. This standard is meant to be universal and applicable towards multiple software development cycles. Organizational tests, dynamic testing, and test management all make up a three-layer model.

ISO/IEC/IEEE 29119-4	This international software design standard will cover testing practices and techniques. These standards are meant to reveal test cases that are meant to acquire data related to system requirements and other specifications. A list of these specific techniques will follow below this table.
ISO/IEC/IEEE 29119-5	Keyword-driven testing is another standard. It defines what a test case uses as predefined keyword. These are often used with certain actions that are required to perform a step in a test case. This will help to identify and create test cases.
ISO/IEC 33063	This standard will contain indicators that will be used for evaluating models or improvement programs, tools, and methodologies.

As follows the below list is for testing of the ISO/IEC/IEEE 29119-4 standard: **[32]**

Requirement and Specification Based Testing Techniques:

- Syntax Testing
- Decision Table Testing
- State Transition Testing
- Cause-Effect Graphing
- Boundary Value Analysis
- Equivalence Partitioning
- Classification Tree Method
- Random Testing
- Scenario testing (Such as Case Testing)
- Combinatorial Test Techniques will include:
    - Each Choice Testing
    - Base Choice Testing
    - All Combinations
    - Pairwise Testing

Testing Techniques Based Upon Structure

- Data Flow Testing will include:
    - All-uses

    - All-du-paths
    - All-p-uses
    - All-c-uses
    - All definitions
- Decision Testing
- Statement Testing
- Branch Testing
- Condition Testing will include:
    - Branch Condition Combination Testing
    - Branch Condition Testing
    - Modified Condition Decision Condition (MCDC) Testing

Testing Techniques Based Upon Experience
- Guessing for Errors

4.2 Realistic Design Constraints

When it comes to designing a product or project, it is important to keep in mind the real-world constraints that come along with whatever it is you are designing. For that purpose, the following sub sections will outline various constraints we feel are necessary to point out for our design.

4.2.01 Time Constraint

A philosopher will tell you that time isn't real, just a construct. A scientist will tell you that time is very much real, but it is relative. Whichever it may be, time is very much a factor for us and the project we are designing. Each member of this group is a student, but also a person. Between each member and their own personal responsibilities, multiple classes, extracurricular activities, family life, and jobs outside of class, time can creep up on you rather quickly. Time management is a skill in, and, of itself. It is a skill we hope to master for the sake of completing our project on time and meeting all other deadlines within our own lives. To help us achieve this goal we will be tracking milestones and attempting to set mini goals along the way as we continue to work and progress designing the project.

4.2.02 Funding Constraint

Everything life costs money. It's what drives the economy in a capitalistic society like the one we enjoy here. It is extremely important to us as a group that we make smart, intelligent, and wise decisions when choosing our parts and materials. We must weigh the cost to project benefit ratio when choosing which parts for what piece of our design. It would absolutely amazing if we could choose the absolute best components for each section of our design, but that is not practical or financially possible. The cost of components can easily add up to an astounding amount when working on electrical projects like the one we have chosen. The best tool for the job is not always the most expensive tool. That is why in our research section of this report we believe we have chosen still some of the best components but with a budget-friendly mindset

4.2.03 Size Constraint

The size of a device can depict the quality, efficiency, and effectiveness of the device. When buying a new TV, consumers usually want the buy the biggest TV available for their budget. But buying the biggest TV doesn't necessarily mean they are buying the best TV for their budget. A bigger TV can have a lower resolution compare to some smaller TVs. Therefore, designing the Plant Nanny with the correct size is important. The size of the Plant Nanny determines what plants can be used, the size of reservoir it can have, the number of features it can have and the quality of the features. For example, a good quality water pump will be too large for our design. Instead, choosing a smaller pump with reasonable quality is acceptable. Overall the size constraint will be intact with creating a well balance design.

4.2.04 Power Constraint

A big factor of our project is that we are relying on a simple wall unit power adapter to convert the A/C electricity from the power plant to a direct flow of current. The power adaptor will provide a constant flow of approximately 12 V DC. Not every component in our project will use 12 V, however. Many smaller sensors and components will need to rely on a step-down voltage regulator to about 3 V or less. Using the power adaptor provides an ease in design as we do not need to worry about the battery level of our device or making sure it is able to provide the needed output.

4.2.05 Part-Availability Constraint

Living in a world where nearly any product we desire is available on amazon and only 2 days away from delivery has made us naïve to the fact that this is not always the case. The availability of certain components is not a factor that we as a group had considered being much of a problem. While doing our research on certain components, to our surprise, we found out that some of these parts were temporarily out of stock. In most normal use cases, this wouldn't be such a big deal. However, we also have the time constraint to consider. A final product needs to be fully designed, tested, prototyped, and finalized in just a few short months. The availability of components is a huge factor. It takes time to order a component, test the component, run diagnostics, etc. Waiting for some components to become in stock again is not a luxury that we have as group for this project. For this reason, it is possible some parts bay be re-considered based on product availability and not because they are the best component for the job.

4.2.06 Soldering Constraint

The parts should be selected carefully to minimize a chance of soldering mistakes. The soldering should be workable with the printed circuit board using manual soldering methods, and this means that the parts need to be large to be maneuverable with hands. The person soldering these parts needs to be able to hold them in place, see what they're doing, and be risk free of injuring themselves. Precision is an important aspect of soldering to get the part on efficiently and without mistakes. The best solder connections are to be made, and this should keep the cost to stay the same because the less mistakes made means the less parts that need to be ordered. The process of working with your team on soldering the printed circuit board needs to be meticulous and straightforward. This will reduce the chance that a connection is wrongly made through soldering and a component could end up shorted. That would be a worst-case scenario if precautions are not taken and mistakes are made while soldering.

4.2.07 Microcontroller Memory Constraint

At the time of writing this Senior Design I document; the team feel that the ESP 8266 Microcontroller has a large enough internal memory for doing all the required processing this project may require. This microcontroller should be able to do any and all calculations necessary as well as read, write, and store all data from our project sensor hub. In addition, we believe the processor has enough memory to also drive the relay for the water pump.

4.2.08 AC/DC Constraint

A constraint we are focusing on for the design of this project is the use of converting AC power to DC power. As seen in the original sketch of this project, it is not particularly meant to be portable. While you could move it around as you wish, the general purpose of this project is to have a sleek, elegant looking device that takes care of your plants for you. We fully believe this product will add flavor to the interior design of anyone's personal home or office while remaining classy and looking great. While it is possible to do the same with batteries, we feel it is more practical to simply rely on power that is already feeding into the home to power our project.

4.2.09 Software Constraint

The process of creating a straightforward and intuitive interface will be vital, but there will be positive creations and negatives drawbacks when creating an application for a phone. The functionality will sometimes be limited by design and vice versa. The important part is to get all the functionality possible while still having the an aesthetically appealing design. The application should give the user a summary of all the information displayed within the app with various choices of what can be done with the hardware or software. The main interface shouldn't be cluttered with every possible option of what to do, but it should have all the basic information of a plant given in the application on display and clicking on these small details should give you the option for more.

The whole idea of this is to keep all the functionality without compromising on design. To keep this kind of design and functionality, the application will have to be looked at from multiple angles and from anyone in the team. The application should have large enough buttons that anyone can press every available option on the screen, but it also needs to be small enough to fit the basic information given. There are other options that can be dealt with, but the main constraints should be dealt with first of what the application needs to accomplish, and how it can do that efficiently and effectively.

4.2.10 Number of Plants Constraint

Plants can be affected by having too many grow in one small area. The purpose of having three spots for plants to grow is to give each plant ample room to get the most direct sunlight it can possibly obtain. If a plant is always in the shadow of another plant, then they are not achieving the maximum nutrients that they can acquire. This hinders their growth. To keep each plant reaching its maximum nutrients potential, a constraint must be placed on how many plants can grow in The Plant Nanny at any given time. This will be mainly constrained by the number of holes for the given pots, but it should also be enforced by the amount of seeds in each pot.

Not all plants will be able to grow and flourish coming from one pot, and that's why the plants will be spread out and able to achieve the maximum amount of sunlight that they can acquire. The size of the plants can also constrain how many plants are available to grow because of how much room they might take up. An example of this would be a plant that spreads out immensely. This presents the other limiting factor besides height which is how far the plant might grow out on an X and Y axis. This could also overshadow the other plants and keep them from obtaining nutrients from the sunlight. The plants could be limited to just one plant due to this limitation. The number of plants for most types of plants however will be limited to three to provide optimum nutrition from the sunlight provided.

4.2.11 Types of Plants Constraint

Height is a major factor for plants growing indoors because The Plant Nanny can only be a certain height and there's not options besides its maximum designated height. Another factor is the type of sunlight given might not be ideal for certain plant types and would require a different type of grow light. Lastly the plant needs to be able to grow from a pot and not have any future growth problems that the light would not be able to envelope. The main goal that this is designed for is herbs, but it should be versatile for several other plants that can grow from a pot. Plants that have vines and other forms of spreading might not be ideal for this setup because the grow light would not be able to cover the full spread of the plant. This can be counteracted by providing a plant that will always be small enough for the full spectrum of light. Although this might be an expandable project, the basis for plants should be herbs or flowers that can fit within a height of around three feet. This will give a plant ample room to grow and will not impede on the light it grows under.

4.2.12 Water Level Sensor Constraint

Our project objective is to create a functional plant growth system that can be used indoors. One of the major points to accomplish this is to water the plants on time. A water level sensor makes sure there is always enough water in the reservoir for this task, but it comes with a few constraints. For one, because water is so important for the plant, we want to make sure that the sensor will not have any harmful chemical reactions with the water. We also want to make sure that the sensor will not cause unnecessary complication when refilling the water in the reservoir, ideally it would be inconspicuous. Finally, we want to make sure that the sensor size is just enough to fulfill the job, we want it to be able to detect water in the whole reservoir but not have it take too much space. These constraints help so that the reservoir can hold the maximum amount of water and be refilled easily.

4.2.13 Social & Economic Constraint

The overall goal of this product to a consumer is to accomplish the task of taking care of a user's plants and provide peace of mind when they are away from home. If the product is overly complicated and/or not user-friendly to set up and operate, then the product may be deemed a failure. Ease of use of this product is extremely important to us. Too many buttons, unnecessary sensors, a non-intuitive smart phone app, and a hard-initial set-up process are all factors that could cause the project not to succeed. We are designing our project with these things in mind and hope to accomplish a simple to use product by the end of senior design.

4.2.14 PCB Fabrication Constraint

The length of time it takes for a company to fabricate a printed circuit board and ship it out to us is not always guaranteed and can vary. This is not ideal, as without a working PCB for our project, we have no project. This means that the design of our PCB is at the forefront of our minds. The faster we can design it, the faster we can put our order in and have peace of mind that we won't be waiting on the last minute to receive our PCB.

Shipping delays are not the only concern with the PCB fabrication process. Defected PCB boards are a very real thing in the electronics world. It is very possible that leads and connections could get crossed unintentionally during the manufacturing process. If this happens our board could become shorted and the circuit will be fried. Causing us to have to re-order a fabricated printed circuit board. For this reason, ample time needs to be budgeted for our PCB testing and multiple drafts and boards should be considered.

4.2.15 Wireless Constraint

Smart devices today, for the most part, all connect to their local wireless network inside of their home or apartment. Multiple devices seamlessly connect or work flawlessly without issue. There might be some concern when it comes to larger or multi-floored places of residence, however. Wireless signals have a hard time traveling through certain materials found in walls or ceilings. There may be more unseen issues, like poor quality signals, inadequate wireless routers, unusually high internet traffic in the neighborhood, etc. The user may be required to contact their ISP for a quality test, purchase a higher speed internet plan, or purchase other gear such as a wireless repeater or extender. Without the network connection, the user will be unavailable to connect to our mobile application and not receive alerts or use other functions of the product.

4.2.16 Water Constraint

Water and electronic devices do not mix. It is very dangerous to both the user and the device should these two interact with each other. It is of the upmost importance that the housing for our PCB and components be securely positioned in such a way that water can access it. This means that we need to make absolute certain that the pumps leading to our 100% leak proof and do not run the risk of spilling into our encased enclosure for the PCB. If water does somehow get through and come in contact, it could destroy our PCB or components or worse. We feel confident in the ability to prevent any sort of leak from happening in our design.

5. Hardware Design

This section focuses on all aspects of the design process on the hardware side of things. This following section will include things such as:

- Overview of the hardware design
- Schematic designs
- Plant enclosure design
- PCB design

5.1 Overview of Hardware Design Flow

This section will briefly go over the hardware flow chart diagram found in section 2.5. To see the research and decision-making process for each component, please their respective sections in Section 3 of this report.

AC/DC Conversion

We decided early on to rely on a typical household wall outlet as our main power source. It provides an ease to the design process and we feel it was the best decision considering our design requires the product to mainly be stationary. The wall adaptor will take the 120 V AC provided from home and transform it to a more usable 12 V DC source. This 12 V will then also be stepped down to 5 V or

3.3 V depending on which component is receiving the voltage. We decided it would be best to use a voltage regulator for this process.

Water Pump

The water pump will be supplied a steady 5 V DC voltage provided by the voltage regulator and be connected to a relay switch that feeds back to the microcontroller. This is what is used to water our plants in our system.

Microcontroller

Our microcontroller is the base of operations for the entire design. It functions almost as the brain of the project. The controller receives power from the wall adaptor that is regulated by our voltage regulator and receives all data transmitted by each of our sensors and is responsible for operates the water pump that keeps our plants alive. It also has the job of communicating via a Wi-Fi network to our smartphone application to send and receive data as well.

Sensor Hub

Sensor hub is a catch all for each of the sensors we have integrated into our Plant Nanny project. The sensors we have chosen will receive data from the environment surrounding them and transmit that data through the PCB to the microcontroller. From there data is then transmitted through the Wi-Fi signal to our smartphone application

Wi-Fi Module

Our Wi-Fi module is the link between the microcontroller and our smartphone application that is in development. The Wi-Fi module receives data from both components and allows the user to monitor data that our sensor hub picks up from its environment and transmit that data back to the microcontroller.

5.2 Schematic Design

The following sections will be used describe and provide schematic captures of the various components used for our end PCB design. Schematics are needed for the following components:

- Power schematic
- Relay schematic
- Microcontroller schematic
- Wi-fi schematic

5.2.01 Power Schematic

The most important part of this design is learning how to distribute the power to ever device. Every device requires a certain amount of voltage and current to operate. The voltages and currents all come from a power source. The power source is a power outlet that has 120 VAC at 60 Hz. In the original design, the 120 VAC will be step down to 40 VAC using a transformer with a ratio of 4:1. Next, using a bridge rectifier to convert the 40 VAC to 38 VDC. In Figure 5.1 below shows a rough draft schematic for the Plant Nanny

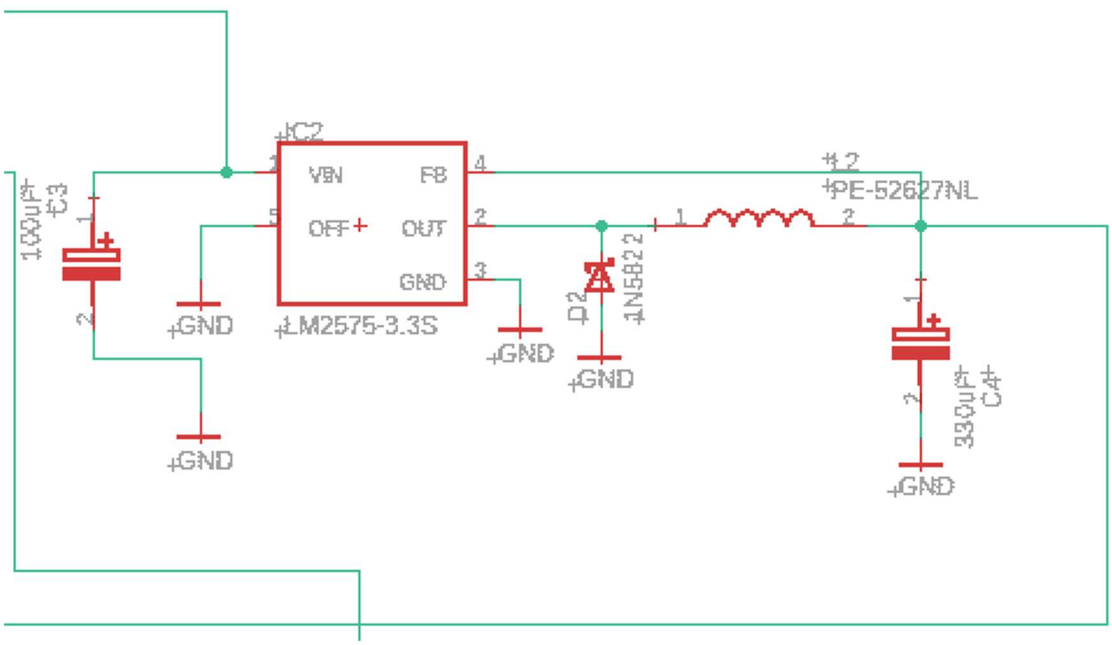


Figure 5. 1: Power Schematic

From the 38 voltage, 5 volts goes to the relay that controls the connection for the LED growth plant light. This connection determines whether the light is turn on or off. This can be seen from a rough draft sketch of the power distribution. However, thanks to the new technology, Texas Instrument has an online application that help develop a circuit that distribute the correct amount of voltage and current require for the project. This program is called Web Bench. By creating different loads for each device that needs the power, Web bench assist with the correct switchers and voltage regulators (LDO) to distribute the require currents and voltages for each device. In Figure 5.2 you can see how the power is going to be distribute for the Plant Nanny.

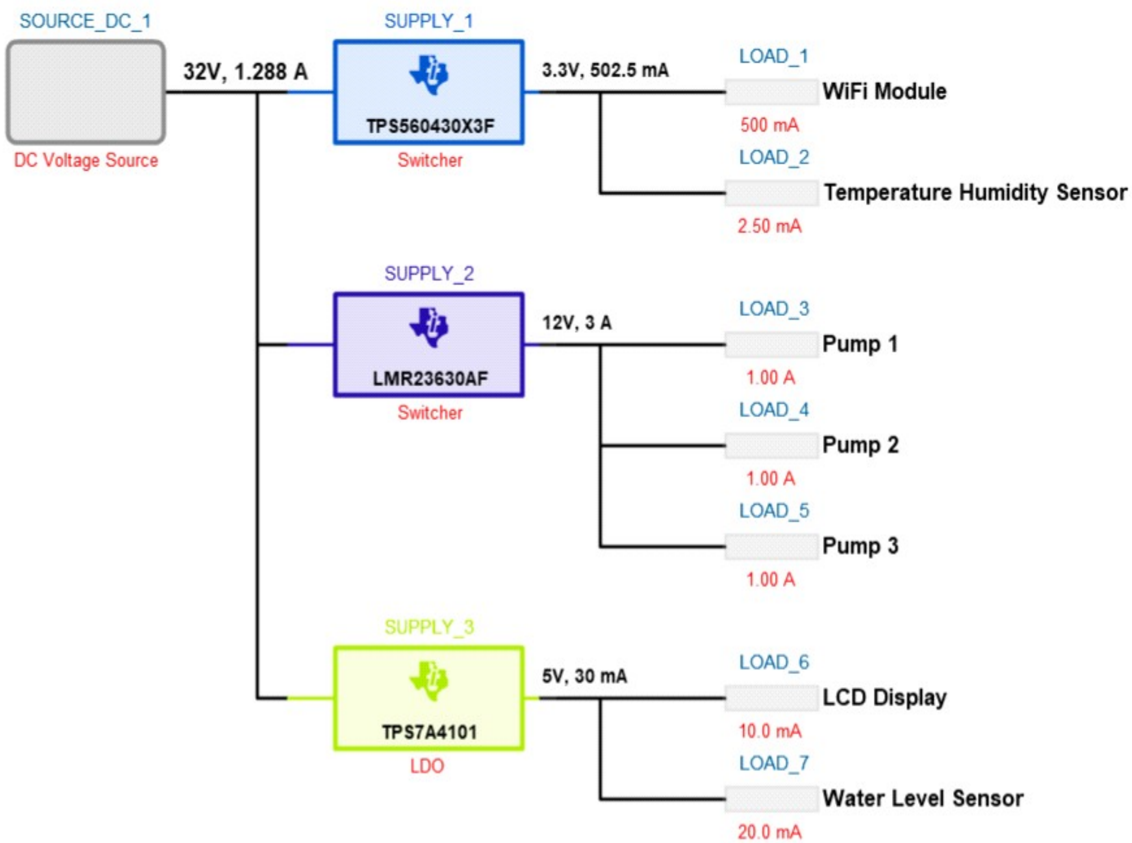


Figure 5. 2: Plant Nanny Power Distribution

In Figure 5.3 shows the distribution of power to the LCD display and the water level sensor. Texas Instruments voltage regulator LM2575-5 regulates the input voltage to output 5 volts at 30 mA with the use of some electrical components like resistors and capacitors. The LCD display requires 5 volts at 10 ma and is depicted as the Rload in Vout_1. The water level sensor requires 5 volts at 20 ma and is depicted as the Rload in Vout_2. Also, as one can see the LCD display and water level sensor are in parallel. Parallel series help maintain the 5 volts at each load while distributing the require currents per load.

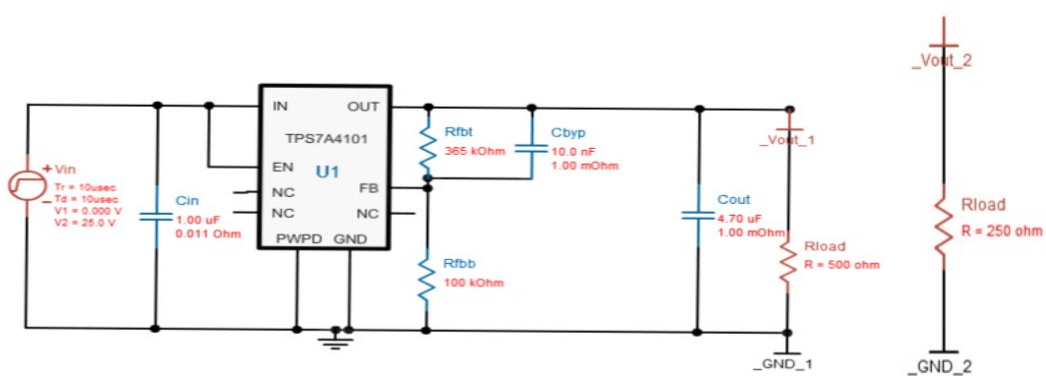


Figure 5. 3 – Power Distribution to LCD Display

In Figure 5.4 shows the power distribution for the WIFI module and temperature and humidity sensor. The Texas Instruments switcher TPS560430X3FDBV outputs the voltage and currents needed to operate the WIFI module and temperature and humidity sensor with the use of an inductor, capacitors and some resistors. The Vout_1 Rload is in reference to the WIFI module and the Vout_2 Rload is in reference to the temperature and humidity sensor.

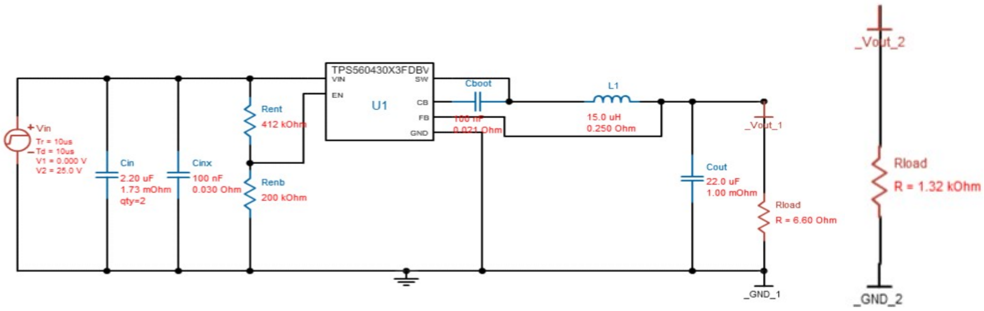


Figure 5. 4 – Power Distribution to Temperature Sensor

In Figure 5.5 shows the power distribution for the water pumps. The Texas Instruments switcher TPS560430X3FDBV outputs the voltage and currents needed to operate the three water pumps, with the use of an inductor, capacitors and some resistors. There are three R loads in reference to the three water pumps. Since the three water pumps require the same amount of the current to operate, they all have a resistance of 120 Ohms. Also, the three water pumps are in parallel to maintain the 5 volts across all three of them.

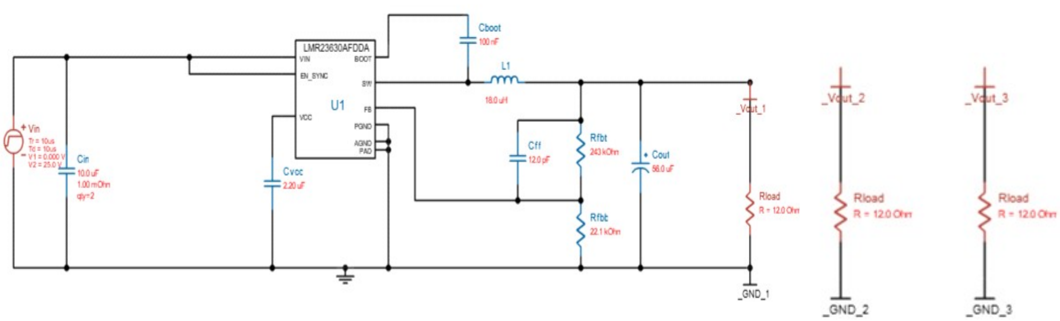


Figure 5. 5 – Power Distribution to Water Pumps

5.2.02 Relay Schematic

The design of the relay will rely off of 5 volts from the power supply and an input coming from one GPIO pin. The GPIO will then be able to send out a 3.3-volt pulse to activate a BJT. This will cause the BJT to saturate and allow a current to pass through it. Next, the current and voltage will saturate the diode which allows a current to pass to our relay switch, turning it on. When the relay switches on, the plant light will be connected to the 120 VAC power source, causing the plant light to turn on. In Figure 5.6, below, shows the relay schematic for the plant the light.

5.2.03 Microcontroller Schematic

The brains of our project rely on our microcontroller, the ESP 8266. The ESP 8266 development board schematic is available for download publicly and will be used as a basis for our microcontroller schematic.

The ESP 8266 will be powered by a regulated voltage of 3.3 V provided initially by our wall adaptor from a wall outlet.

More design details about the schematic will be made available to the report further on in our design process this Fall in Senior Design 2. For reference we would like to depict the development board microcontroller schematic pictured below (Figure 5.7).

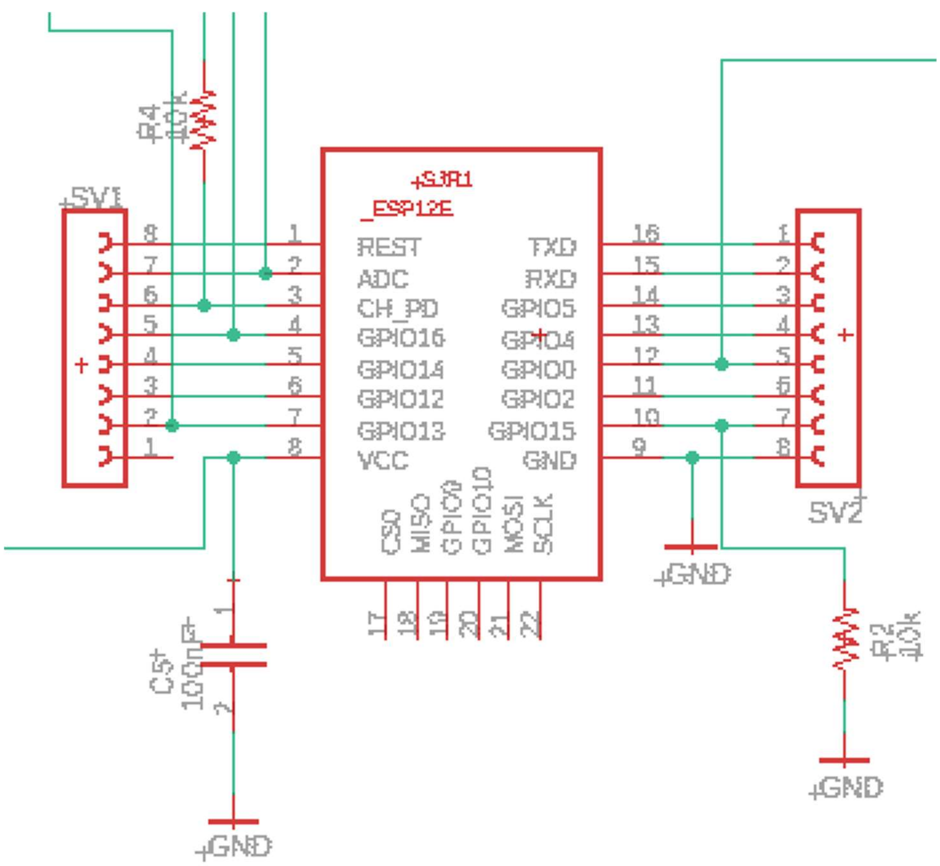


Figure 5. 6: ESP 8266 Schematic

5.2.04 Wi-Fi Module Schematic

The microcontroller we have chosen, the ESP 8266, has a built-in function for wireless communication capability. The exact Wi-Fi schematic we plan to integrate into our project design will be added to this living document we reach that point of development this Fall in Senior Design 2.

The built-in Wi-Fi module in the ESP 8266 will utilize the RX and TX pins to transfer data between its Wi-Fi and MCU parts. This is expected to happen very rapidly as they are already integrated together. The Wi-Fi module will then transfer all data it receives from our sensor hub to our smartphone application still in development.

Even though the MCU and Wi-Fi module are on the same board, we felt as a team that it was important to break it down into sections to better clarify how the two worked and their functions. Having them being integrated together will allow us to more easily implement our design onto the PCB when we continue to Senior Design 2 this Fall.

A Wi-Fi schematic created in our schematic design program will be provided below to better illustrate the design principles along with more detailed information regarding pins and control lines when we get to that this Fall.

5.3 Plant Enclosure Design

The enclosure design is an extremely important process, especially when you consider we are mixing electrical devices with water. These two things must not come into contact with each other. At the least, it will damage the components and cause it to no longer function properly. At worst, it can cause sever health problems, or even death to the user. As such a proper case enclosure for the plants are of an up most importance. It was buit using 2X6 woods and screws.

There is a standardized rating system when it comes to enclosure water protection. The Ingress Protection, or IP, rating is internationally a recognized waterproofing standard used in nearly all modern devices or cases. The IP rating consists of two numbers, for example: IP 56. The first digit is its resistant level to dust and tiny particles or foreign objects. The second digit refers to its protection from other liquids. Below are two tables indicating the different levels of protection for each number (Table 5.1 and Table 5.2) [37].

Table 5. 1 – IP Rating (first digit)

IP Rating for Dust (First Digit)	**Description**
0	No special protection. Not rated for protection of this type
1	Protection from solid objects greater than 50mm in diameter
2	Protection against objects not greater than 80mm x 12mm
3	Protection from entry by tools with a diameter of 2.5mm or more
4	Protection against solid objects larger than 1mm
5	Partial protection against dust that may harm equipment
6	Totally dust tight. Full protection against dust and other particles

Table 5. 2*: IP Rating description (first digit)*

IP Rating for Moisture (Second Digit)	**Description**
0	No Protection
1	Protection against vertically falling objects
2	Protection against water droplets deflected 15 degrees vertical
3	Protected against spray up to 60 degrees from vertical
4	Protected against water splashes from all directions
5	Protection against low-pressure jets of directed water from all angles
6	Protection against direct high-pressure jets
7	Protection against full immersion for up to 30 minutes
8	Protection against extended immersion under high pressure
9	Protection against high-pressure, high temp jet sprays

Due to the design of our project we hope to aim for an IP rating of at IP 64. This will give us full dust and other particle protection while also giving protection from any accidental splashes or spills that commonly occur inside of a household.

To achieve this, we will make sure our electronics box is fully encased in a water-tight box and kept separated from the water tank reservoir.

5.4 PCB Design

The schematics and PCB were designed using EAGLE. Below you will find a broad schematic of all our functional parts as well as an image of our finished design in EAGLE.

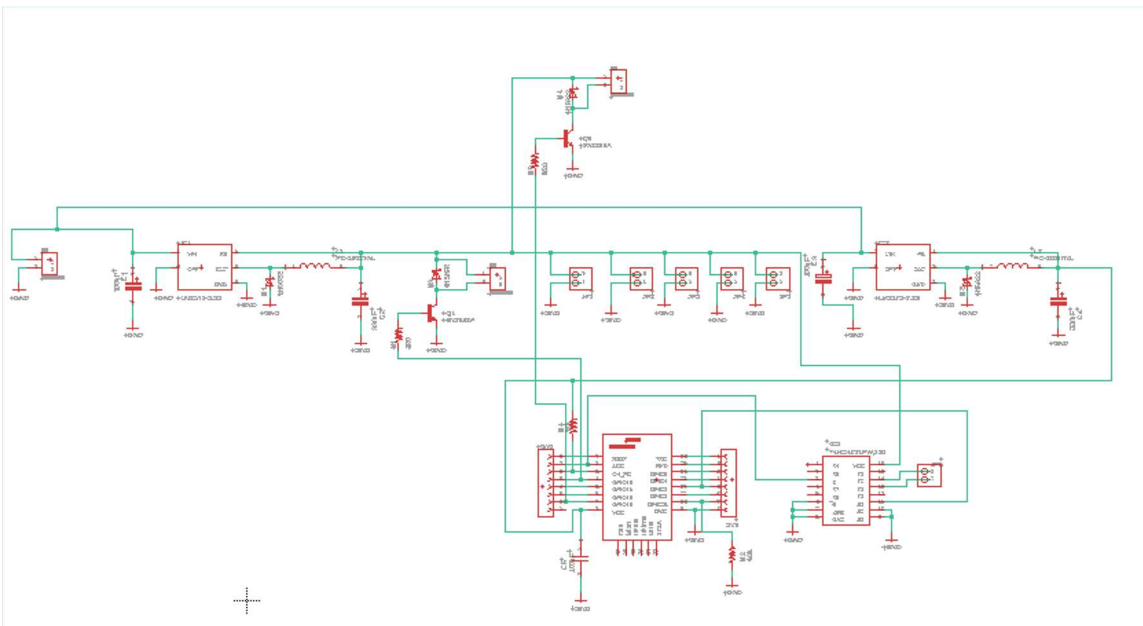


Figure 5.8: Overall Schematic

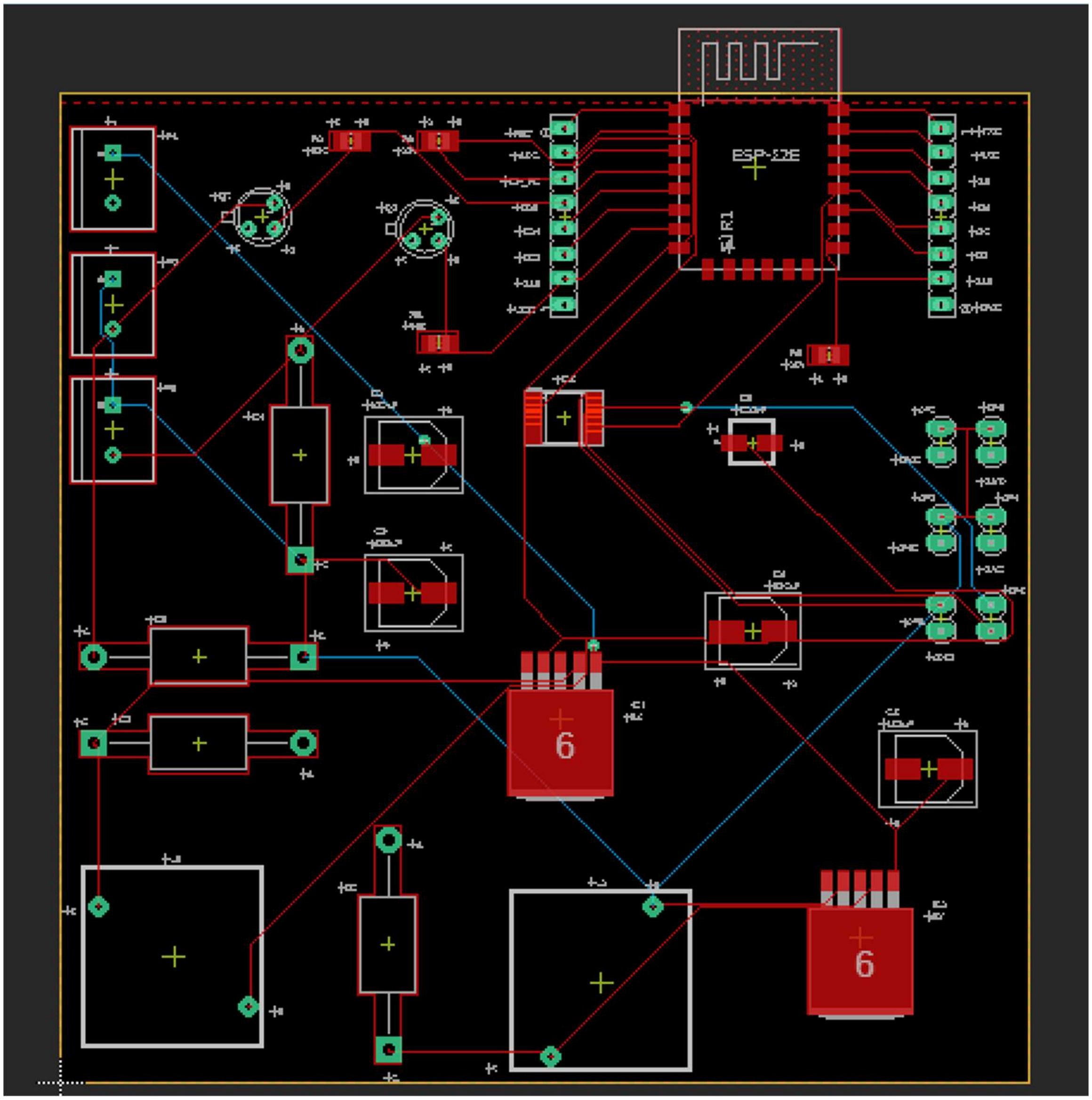


Figure 5.9: Final PCB

6. Software Design

Software design envelops many areas of interest that include both our hardware and software application. The main purpose of these sections is to further discuss how all this design comes together with the hardware and what steps were taken to decide what would be best. The first section will be methodologies which will digress into what the main purpose of this software is and what it's meant to do. The following section talks about the different tools and applications used for the software design, and why certain applications were chosen over other options. The next portion involves microcontroller software and how this directly affects the hardware.

It mainly discusses what applications were used to achieve the full functionality of what we're trying to accomplish. The section after that is referred to as the smartphone software section which discusses exactly how everything fits together to make the phone application a success, and exactly how it can work to deliver results. Another important section is the design and functionality of how the user interface interacts with the programming, and how this influences the final product. The last section involves a user-interface prototype that directly demonstrates and explains what the app will look like and how it will function with the hardware, and this part should be useable for anyone to look at its functionality.

6.1 Methodologies

The main goal of this project is to build a prototype of The Plant Nanny, and these are the different methods that were taken to allow us to create this product. The process involved numerous ideas all strewn together of what exactly the final product should be. Originally there was no initial plan to have an app, but eventually an app was placed into the mix to properly display data. These were choices made through frequent development meetings before the making of the project. The group took on an agile form of communication, and this positively affected the development.

Decisions were constantly made on what to add to the project and what forms to change. The software development process began with the microcontroller and what functionality it was designed to have. The different factors were heavily debated on what exact sensors would be used, and as the meetings progressed more sensors were added to the set up. The process continued to the phone application as more features were imagined on the possibilities of what could be done. As the group conversed the ideas became more apparent than they had been.

Although no product was being created at the beginning the initial planning phase of aspect was always still a conversation topic. The point of discussing weekly was to primarily keep in touch with what our main objectives were as well as additions that could work or would not work with our hardware and software. The phone application became a topic on what features could be added as well as which features were not necessary. Design decisions were constantly being made, supported, or argued. This helped to build a clearer picture of the exact performance and features that were desired from this project.

The purpose was clear of what these meetings entailed, but that was during the design phase. The meetings had additional coverage of the time scheme layout of how other developmental aspects would be addressed and when. Not only would the discussions be about design aspects, but it would also cover implementations of said design and testing of the prototype. This methodology of product development will be referred to as incremental because of how it has a linear and assembly line type structure. Certain methods will always be upheld within the development process such as:

- The project will have subdivisions branching from a main portion. The main portion will also be subdivided, but these parts will take priority in the initial development phases in order to have a working product.
- That foundation will have the other subdivisions that will be branches, and these will still be handled as additional parts of the project.
- This type of working will also be linear as every part is dealt with individually until a working system is developed as well as the smaller parts of the project.

The process of development should take time because of all the individual components that need to be taken care of. Every part must work together properly, and it is expected for newer added parts in programs to have negative effects on other parts that have already been finished and implemented. Through all of this and careful analysis the project should be complete without too many compatibility issues because of modularity and linearity of how the development process will be handled.

6.2 Tools Used for Development

Programming required different software as well as certain types of hardware to properly work. The main software used for developing the phone application was MIT App Inventor 2. This was a free software offered online mainly used for Android app development. The software used for hardware development was mainly the Arduino IDE because of its collaboration with the hardware that was being utilized. Arduino IDE is a free software offered online that offers a basic programming experience that is easily manipulated for whatever purpose is required. Both programs have debugging portions of their software that will aid in the completion of the software development process for this project.

Other programs that were used during the development process include online Microsoft Word documents to create the document that this is written on. This was chosen due to its flexibility with constraints for the formatting of the document as well as its accessibility for everyone to collaborate online. The only other program used for this project was through GroupMe which was mainly used to communicate with one another when the group would meet and any problems that occurred with the project.

The phone application was strictly Android based with no other phone integration. It was mainly this to combat costs as well as its versatility to work with a plethora of phone models. The software offered complex support to get an application a sense of design depth. It contributed to the exact developmental purpose that the software was designed for. MIT App Inventor 2 creates the layout that is desired as well as the different measurements that will be uploaded to the app from the setup of the plant.

This was neatly overlaid and adjusted by the user on the application. Not only do you design in MIT App Inventor 2, but it also gave the opportunity to implement everything and test it through a virtual phone. This was an example of how the program would operate on a phone as well as any bugs that could be seen immediately. The style also displayed and made visible any types of overlay problems.

The Arduino IDE was used for its simplicity in what is required for this project to do as well as how versatile it was towards different platforms. The IDE supports Windows, Linux, Mac OS X. This means that it could be portable from machine to machine so that any person could work on the program from any computer. The program would also allow debugging which could see why a sensor was not working, or why the project did not perform to expectations. This would become invaluable as the project had more added onto it because one thing might not have worked do to another portion being added on. The team would continue to design using this IDE as a main program for the hardware and sensors due to its versatility and understandability.

6.3 Microcontroller Software

The microcontroller software needs to be designed in such a way that all sensors and pumps will operate according to plan. In order to do this, the team developed a high-level flow chart, similar to the one seen at the beginning of this paper. Instead of being as broad, this figure (Figure 6.1), pictured below, shows a general overview of how our software will function assuming no compilation errors or sensor errors occur in our testing.

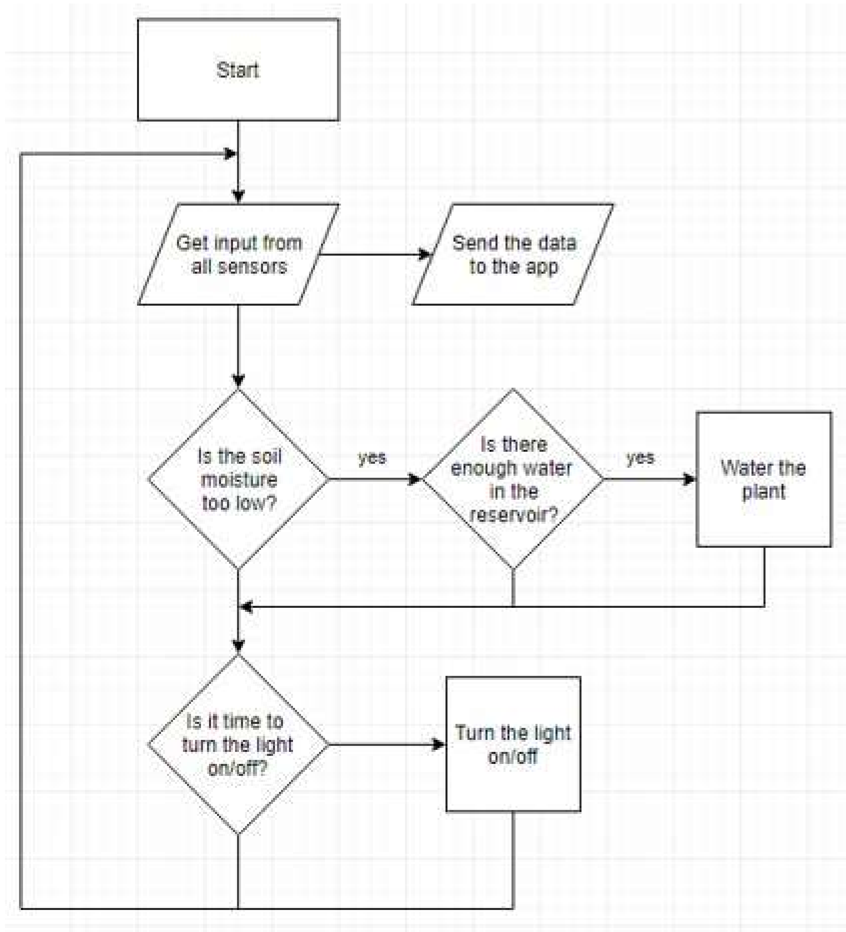


Figure 6. 1– Software Flowchart

6.4 Smartphone Software

The current software production was based around the Android environment. This was done due to the wide variety of android phones and software versions available. Having this variety allowed for a more universal standardization of this phone application. This was chosen over IOS due to issues with time, cost, and versatility. To accompany this choice of software the program itself would help to build the application. The program that was utilized was MIT App Inventor 2. It was chosen for its free domain use for any who wish to develop a phone application. Using MIT App Inventor 2 over other options would also lead to the versatility in the selected Android device to be used. Although XCode would have been a good choice for IOS, it’s not practical for its application here because of some limitations.

To program with XCode would require access to a MacBook as well as knowledge of their specific programming syntax. Although this could be learned, it would prove to be a simpler task to use existing Java programming knowledge to learn how to control the functionality of the phone application. Both would work for the purpose of this project, but one will provide more ease and functionality for the scope of this creation.

Another note was to use Kotlin instead of Java for the project because Kotlin is a newer language, but since the app will be developed for Android 5.0 newer programming languages are less of a worry. Compatibility and versatility will be more widely looked at and sought after. Java will perform everything that is required and will therefore be the standard when it comes to development.

Figure 6.2 below displays a very early example of what would be displayed on the home screen of the phone application. It would show basic statistics of what is going on in the plant's environment at any given moment as well as if the setup for the Plant Nanny needs any attention towards its water supply or lighting. Although light intensity might now seem like an important addition to the application it would be useful towards detecting if the lighting fixture is working at full capacity or if it's functional at all. Another additional feature could be a remote off switch.

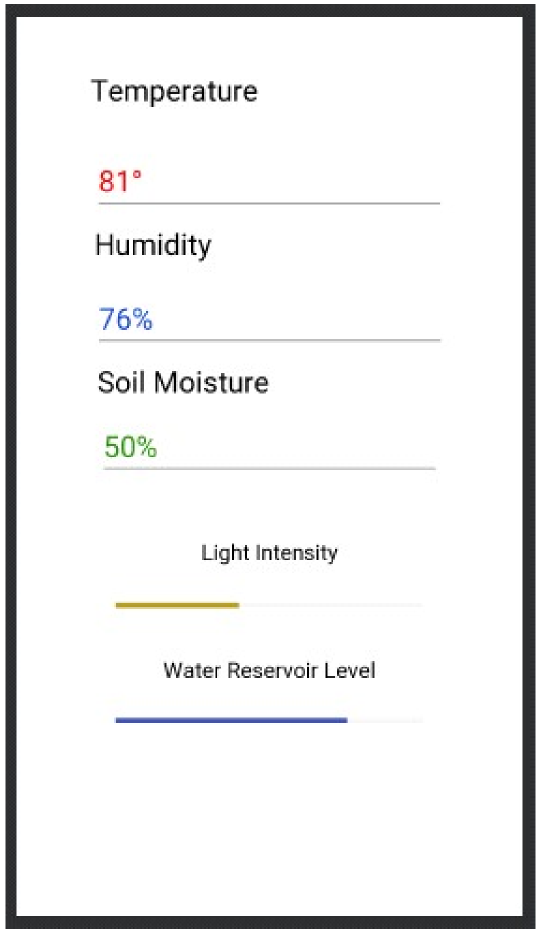


Figure 6. 2: Basic Application Display

If the plant setup is forgotten on a business trip and the light setup is left on there's always the possibility of a fire hazard, and in this case you would have the ability to turn off the light fixture from anywhere to avoid this hazard if you're going to be gone for a long period of time.

6.5 Design and Functionality

User interface was one of the most important parts to an application. This is where the user and the programmer need to understand each other. That's why the user interface that would be used needs to be intuitive and easily understandable. To get straight to the point and get the message as well as the information across to the user immediately while keeping it versatile enough to be used to its fullest extent.

The Android application has a couple of layouts such as a constraint layout to properly place objects and texts where they can be visibly seen and kept them in an easily readable format. The usability of this application is of great importance towards the overall success of this project. The application has multiple functionality for what its intended to be used for. The different views of what is the application involves a main tab that would display a lot of information, a view for controls for some of the main electronic components, and a view settings or customizable parts of the app. Figure 6.3, seen below shows a rough Entity Relationship Diagram of some of the main functionality of the application.

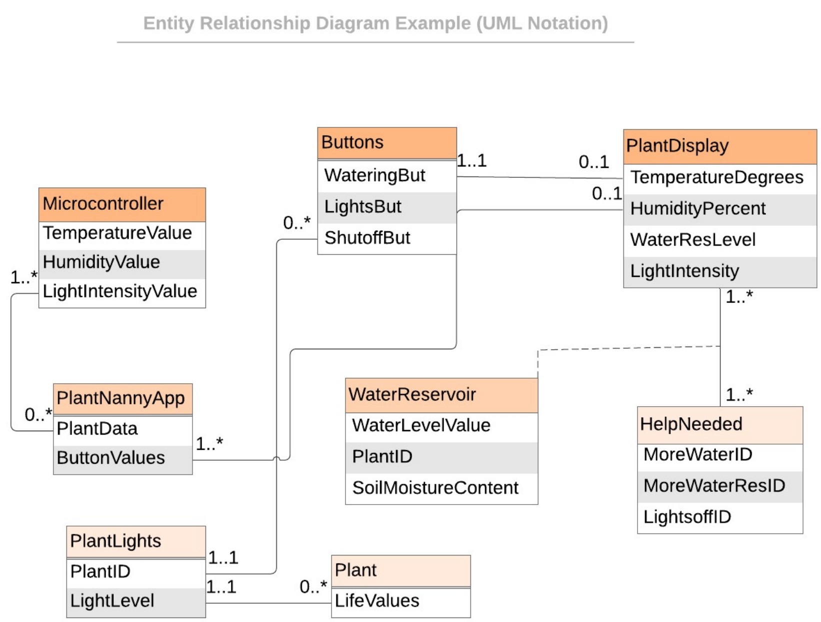


Figure 6. 3: Entity Relationship Diagram

The main view would display basic plant data such as temperature and humidity. The other views would include button views that distinguish possibilities of what you're capable of doing with the internet connection of the phone application. This would revolve around the water reservoir such as manual watering from far away and turning the light fixture on and off. The plants would have plant ID's that would give a general idea of where the plants are and what water feeders are above them. This would give more exact feeding and light level placements.

Another view is customizable options such as the lights having a setting that includes turning them on or off at certain times. A timer to let you know how long the lights have been consecutively on. The application would provide a general idea of what is needed as well as characteristics involved with them. For instance, the plants have moisture sensors that tell through microcontroller functions that the plants need more water added to them. That is how the functions work with the application to successfully create a working environment that allows for plant care from a mobile perspective.

There are parts that are more important than other functionality of the application such as the basic information of what the plant is experiencing in its environment. The flowchart in Figure 6.4 below shows that the main view will be the first creation in the development process to ensure that the sensors are set up properly and information can be sent to the application from the internet. The next part involves the notifications of when the water reservoir is low on water, or the lights are off. That will be built upon the main view to simplify the space and what the first statistics should be when you open the application.

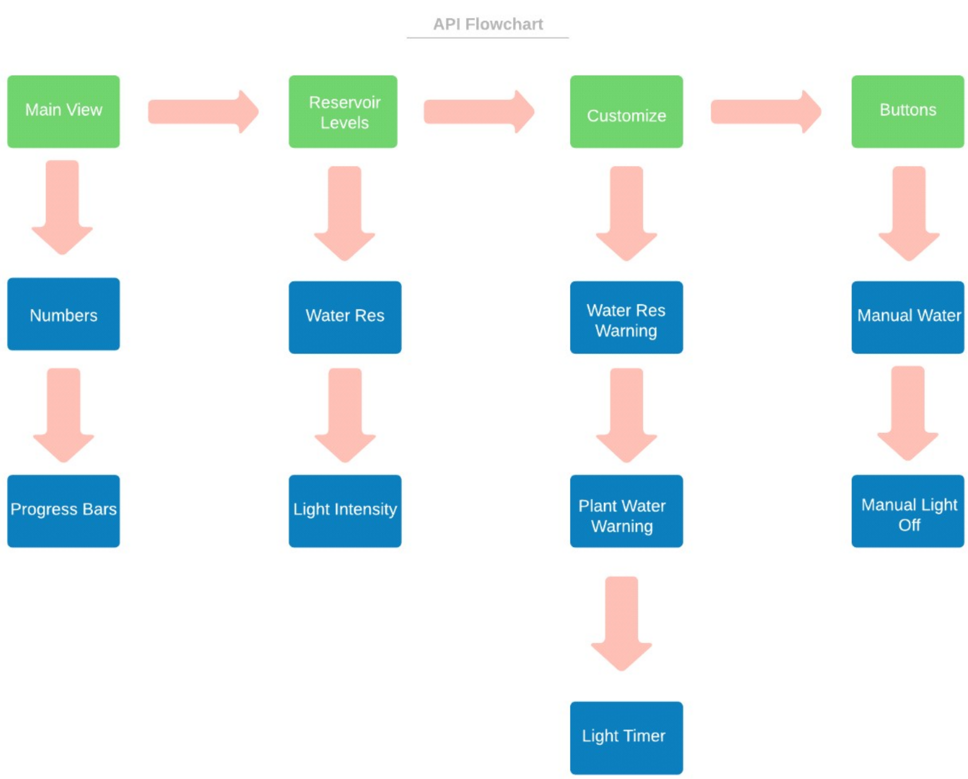


Figure 6. 4– API Flowchart

The next view includes the customizability of the application such as when the water reservoir will let you know that you're low on water and need to refill the tank. The other use it has is at what point the soil is too dry and needs to be watered. This leaves a basis if the option to manually water them is chosen instead of through a timer. The last is an option of how long and when the light fixture should be on. This is done because the light a plant requires can vary, and some will need more or less than an average day of a certain location. The customizability becomes important towards plant maintenance.

The last view involves buttons for various tasks that might need to be accomplished if automatic functionality fails. This includes a button to manually water the plants. It activates the water pumps from the reservoir for a standard amount of time to ensure the plants are properly watered if the timer is not functioning properly, or if the plants need to have more water. This also means the timer needs to be adjusted to allow for more water in any given time period.

The other button is for a light on and off type of manual functionality. That would be used in the case of a light fixture being left on for a long weekend when the user is away for a long period of time. They would be able to turn the light fixture on or off to prevent fire hazards. The other side of the spectrum would be if the light needs to be manually turned off due to a plant's long exposure to sunlight.

The button view is meant to be more of a safety feature for accidents that might occur due to negligence or misuse. Forgetting is a common problem with certain tasks, but the purpose of this view would to give complete control to the user to ensure that if automatic functionality is a problem then they have the power to turn off the system or turn it on.

The application is both functional, stylish, and straight forward for the purpose of the user. The user should enjoy opening the app and looking at the most important data displayed right in front of them in a neat and concise format. It will be able to do any task the user might have such as setting timers for on and off functionality as well as allowing for manual use of the water and lighting. The application should be an all-encompassing main point of origin towards all information and functionality of the Plant Nanny.

7 Testing Plan

Testing is one of the most important steps in the design process. It is where we can find out if the product will operate as initially thought out. It is where we discover if the device is working properly, if it is working safe, and if any errors are found we can correct them in a timely manner. Without the testing process, the design could end up a failure and the team would be left with a product that did not work.

This section goes over:

- The stages that the hardware was tested
- The software testing and debugging procedure
- How the team plans to demonstrate a working product

7.1 Hardware Testing

These first sections will go over the hardware testing plan. The hardware components are as follows:

- AC/DC power adaptor
- Microcontroller
- Water pump
- Relay circuit
- Sensors
- Power circuit
- Wi-fi module

7.1.01 AC/DC Conversion

The first and probably the most important test in our series of tests is to make sure our power adaptor is working properly. If for any reason this hardware should be faulty or proved to be not functioning, then nothing else in the project will function. It is the power source of our design and without it no components will ever receive any power. Fortunately, this is an easy test.

First, we will verify the wall adaptor is not damaged in any way. We will inspect and look for signs of damage to the adaptor and discard if any sign of danger is found. We will also inspect for deformed housing or soot as these are signs of an overheated or burnt adaptor. Next, we will verify that the outlet is receiving a voltage. Using a voltmeter, we will verify the outlet is indeed functioning. Once the adaptor is plugged into the outlet, we will attach the voltmeter leads appropriately and take the reading. If the voltmeter reading is the same as what are adaptor is rated for than it is a pass. If not, then the adaptor is faulty, and we will need acquire a new one.

7.1.02 Microcontroller Testing

In order to make sure our microcontroller will work properly for our project; we will first test it. We begin with a basic AT test. This test is done by sending a signal to the microcontroller from a PC, telling it to show it is paying attention and is ready to execute. We will then go through the I/O ports and calculate that the is current flow and it is not a short circuit. We do this because we want to identify which ports may be defective before we assemble the parts. Once we are done, we can start testing the wi-fi capability of the microcontroller. We do this by AT+CWLAP into the command window and it will list available wi-fi access point on the microcontroller. If it works well then, we should be able to find a new WLAN on the PC. Finally, we test the memory of the microcontroller. We use some code to make sure that that MCU can store and retrieve the correct data. With this we have finished a very simple and basic test that tells us that the microcontroller is functioning well.

7.1.03 Water Pump & Relay Testing

The pump that the team selected was chosen because it stated it would deliver the water flow, we needed at a 5-volt input. In order to test that this is working properly, we plan to drive the motor with a 5-Volt DC power supply and check whether the water is indeed flowing at the needed rate. Assuming this test is passed, we will then integrate our relay circuit that drives this load and again make the test is passed.

In order to properly test the relay circuit, each part needs to be tested individually in order to insure a safe operating design. A diode is connected to a small power supply and also connected to ground. We then will check the current flowing through it and if there are any breakout voltages. The transistor will be tested in a similar way by setting up a common collector with the diode attached to its connector and to ground. We expect that when a voltage is applied, the base current flows through it and can drive the current through our diode. The last check for the relay test will be having a higher voltage applied to the switch terminal to ensure it turns on the connected load of our water pump.

Once the water pump and relay circuit have been confirmed to be operating as expected, they will be joined together and then tested off of the microcontroller. We will utilize a power supply providing a 5-volt DC attached to the top node between the diode and relay terminal with a 3.3 DC voltage being sent through the base of the transistor. The test will be considered a success if the water pump turns on. It can then be attached to our microcontrollers GPIO pin.

7.1.04 Sensor Testing

Each of our sensors will be tested individually on an Arduino development board to start with. Once each sensor is verified to work independently of one another, the team will start to combine all the sensors onto one breadboard. This test should confirm that all sensors are indeed working together as a whole. We hope this testing phase will be one of the simplest as we are using the Arduino development board. The Arduino board comes with simple plugins to GPIO and power pins. We will program the microcontroller to rad and output sensor data to a nearby computer that we attach to the Arduinos USB port. Analyzing the data, we receive is the most important part of this test. Any weird or unexpected values could indicate a bad sensor. We need to be 100% positive that all sensors are working correctly so we can finalize them on our PCB design. Several individual sensor tests are outlined below.

The DHT11 temperature and humidity sensor utilizes four pins and sends a calibrated digital signal from the factory as an output. We will hopefully not have to get to complex of a code to get a proper reading from the sensor once we initialize the serial communication. We plan to test the sensor by connecting one pin to our power supply, one pin to ground, and another pin will be used as the data signal. The DHT11 datasheet indicates that one of the four pins are null and not used for anything. We will first supply power to our sensor and then wait approximately one to two seconds before we give it any instructions. The sensor will initially be in its unstable power up phase and we want to make sure we do not interrupt this. Once the allotted time has passed, we can begin its test.

When testing this sensor, it is important to realize that a single cycle of communication between the DHT11 and our microcontroller takes about five milliseconds. It is expected that instructions issued prematurely (i.e. in the middle of a request for data) will most likely cause errors or garbage data. Knowing about this beforehand allows us to hardcode a small delay in order to properly test the sensor. Once the sensor is verified to be connected correctly, the serial channel will be set up and we will use the Arduinos digitalRead() function in order to grab any data the temperature sensor picks up. If working correctly, the DHT11 should send us 40 bits of data, with the higher value bits being transmitted first. These 40 bits of data is divided into five octets.

- First Octet – Integer portion of relative humidity
- Second Octet – Decimal portion of relative humidity
- Third Octet – Integer values of temperature
- Fourth Octet – decimal values of temperature
- Fifth Octet – Eight-bit checksum

The fifth octet checksum is used to verify our readings and should be equal to the last eight bits of the four preceding octets added together.

The figure below (Figure 7.1) pictures a flow diagram of the testing procedure for our temperature sensor, the DHT11.

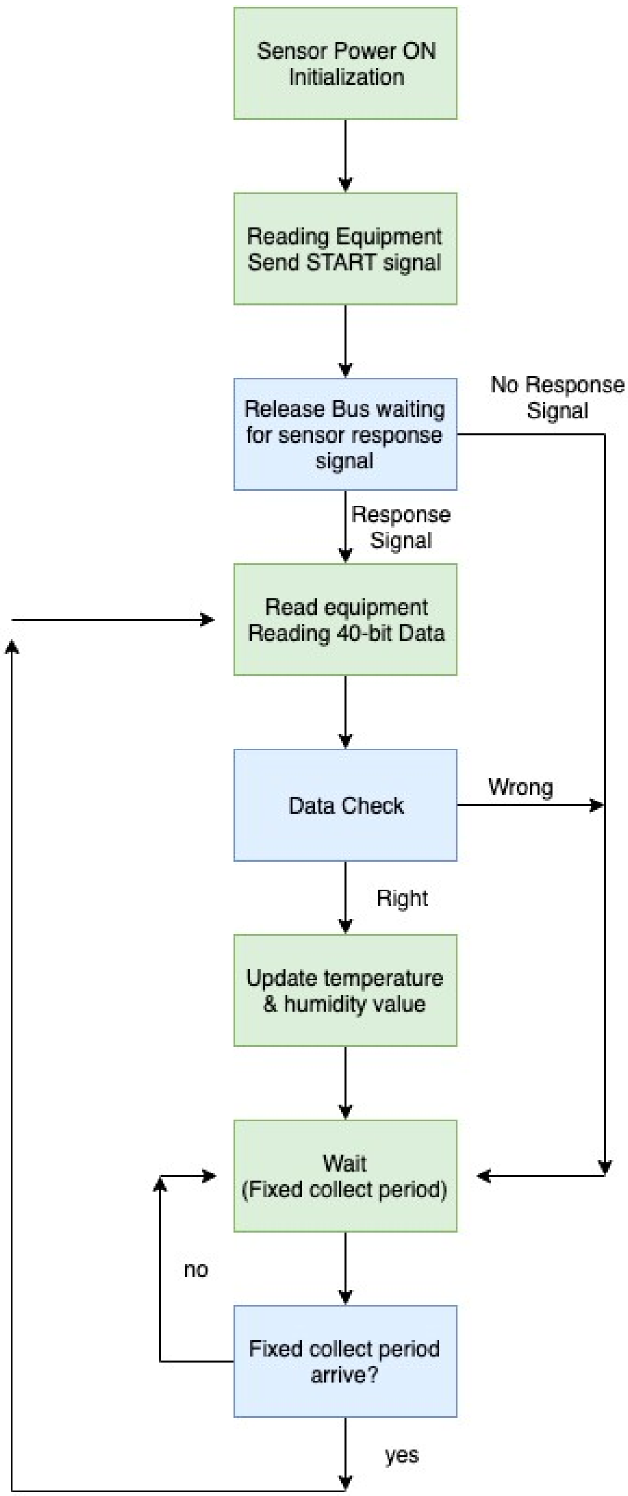


Figure 7. 1: DHT11 Data Collection

7.1.05 Power Circuit Testing

Our power circuit tests will be two-fold. The AC/DC conversion and the voltage regulator. The AC/DC conversion can easily be tested by plugging in a wall adapter and using a multimeter to see the DC voltage output. This reading should be of 12 V so as to supply enough power overall. After Gabriel did the testing at home using a Craftsmen multimeter, 120 to 12VAC transformer, and a bridge rectifier the outcome ended up being 13.13 VDC as suppose to the 12V assumed. In Figure 7.2 below shows the experiment Gabriel did at home.

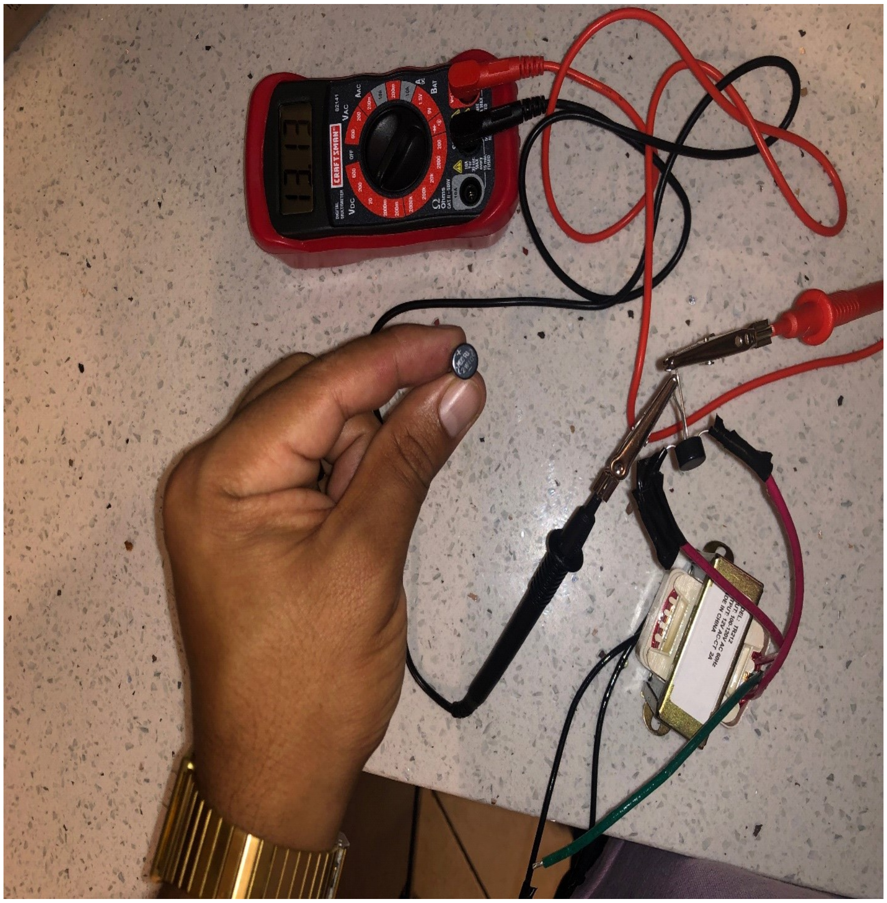


Figure 7. 2 – AC/DC Test

In order to test the voltage regulator, a DC voltage will be applied to the input side of our regulator. The input from the power supply will be between 5 and 12 volts, to represent the AC/DC power source. This should be more than enough voltage to have the proper output of 3.3 volts of our regulator. If we are not seeing 3.3 volts from the output of the voltage regulator, then we will need to add a voltage divider to the output to ground and take its measurement. Once the desired voltage has been reached, we can move on to the full circuit test.

The full circuit test will take place once the voltage regulator test has passed. Using wall outlet as a power source, we can attach the regulator to the circuit. Again, we measure the output of the voltage regulator to ensure a DC of 3.3

Volts, utilizing voltage divider resistors as needed. Once we reach our desired output of 3.3 V, the power circuit will have passed all testing procedures.

7.1.06 Wi-Fi Module Testing

The Wi-Fi module will be tested on the Arduino development board. The power will be supplied using a DC power supply to maintain a constant power and voltage and ensure no fluctuations occur. It is important to note that the Arduino Development board only outputs about 50-60 mA of current through its 3.3 V pin. The ESP8266 requires over 100 mA of current when it is at peak performance. The module will be mounted on a breadboard and then pinned into the correct slots for its TX, RX, and ground node.

We then will use the Arduino to run a basic script to fetch data from a random website. If that data can be retrieved properly, it will post the data to the user via terminal on the computer that is connected to the Arduino development board. We will verify that the data received is in fact correct, and if so, we can be assured that the module is in working condition. If the data is corrupted or wrong than it is possible a signal connection, or communication error has occurred. If no data is posted than it is a sign that the device has failed. A new one will need to be purchased if this is the case.

7.1.07 Final Testing Table

The table below (Table 7.1) is a summarization of all testing procedures mentioned above and how each test can pass or fail. If a component fails the test, then that component is faulty, and the team will need to purchase a new one immediately in order to stay within the time constraints. Once each test has been confirmed to pass, the team will implement them all together in a prototype board or bread board. Then after the prototype board is confirmed to be working as well, the final PCB design can be assembled, soldered, and fabricated and one final test can be admitted.

Table 7. 1 – Final Testing Table

	Pass	Fail
AC/DC	Multimeter reads DC voltage from a wall unit	Multimeter does not read the correct DC voltage
Microcontroller	Can receive input and push an output. Able to power on. Displays information to the user from its sensors Operates at low power	Does not do one of the following: Receive input/push output Power on Display information
Relay Circuit	Circuit gets switched by input voltage Can drive the water pump through relay terminal	Circuit is not turned on by the input voltage Pump is not driven by the circuit
Power Circuit	Able to convert 12V to 5V and 3.3V and keep constant current	Unable to convert voltage or keep a constant current
Wi-Fi	Transmits data from website to Arduino	Does not transmit any form of data between PC and Arduino

7.2 Software Testing

These last two sections will go over the software testing plan. This includes how the hardware interacts with each portion of the project as well as how the phone application will be used with statistics pulled from the microcontroller software. The software testing sections are as follows:

- Microcontroller software
- Smartphone application

7.2.01 Microcontroller Software

The microcontroller software was tested on a development board with the software embedded within the processor and programmed memory. The board can run the software without being plugged into a computer, and it should be usable on its own accord. The focus of the software was first to be on if the code runs successfully on the first attempt, or if it has trouble with properly connecting with the microcontroller. After this other preliminary test should be conducted such as:

- Testing for fully functioning parts being detected by the program and if there's any disconnects between the software and hardware
- Sensor Accuracy
- Sensor Reliability
- Polling Timing
- Connectivity with Smartphone Application

Testing for correct operation occurs immediately into the testing. This is to ensure that the microprocessor is working to the best of its ability. Essentially no other testing can commence until the unit is properly functioning. The crucial step of getting the hardware and software to communicate stands as a top priority for implementation of the program. This was done by simply turning on the hardware, uploading the program, and watching the output display on the app.

Sensor accuracy proves to be a task that requires precision on both the software and sensors parts. Accurate results are to be sent to the smartphone application or LCD display which requires the information being sent to have precision. The sensors must be tested precisely using other accurate sensors that have no reliance on the program embedded in the microprocessor. This will be done through means such as a thermometer, visual aid, and other types of practical measurement. This can be conducted in any environment if the environmental variable values are known beforehand. Therefore, if a test for humidity is done in a sauna the expected result should be one hundred percent humidity. That is one example of how the precision and practicality of the sensors can be tested.

Sensor reliability is another important aspect of microcontroller software. The software will constantly be refreshing data from all the sensors and it's important for the microcontroller to detect if a sensor has disconnected or has broken. This could affect the system by distributing false information if the problem isn't properly picked up. The reliability can be tested by running other tests as well as an endurance test of a couple weeks to see how long the microcontroller and sensors can keep up with continuous polling.

Polling timing involves the ability to set the timing intervals of when data is pulled from the sensors, and how often this polling will occur. Realistically, polling would take place more than once a day and therefore it needs to be tested that these polls can take place at any given interval up to ten seconds. This will show that not only can you pull information from the sensors rapidly, but it will also help with durability testing of the sensors and microcontroller. If the polling is done one hundred thousand times than this shows that the reliability of the sensors is up to par as well as the capabilities of the microcontroller.

Connectivity with a smartphone is a main feature of this project and is a pinnacle test point that needs to be shown and examined. This test will involve the phone application and a smartphone with an internet connection. The point is to make sure the phone can connect with the microcontroller and the microcontroller can transmit correct and accurate information to the application. This can be tested by running the application on the smartphone and constantly refreshing the data to monitor changes. This will cause the microcontroller to keep polling from the sensors which should give accurate information. How to test this is pictured below in Figure 7.3.

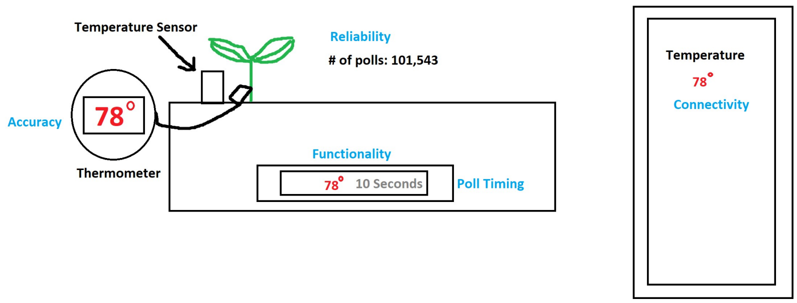


Figure 7. 3: Sensor Demonstration to Smartphone App

Figure 30 above shows a simple representation of all these test characteristics for microcontroller software. These all correlate together into how this project works and operates properly. The tests for the microcontroller software will be carried out at a house with an internet connection, the development board, an early prototype of the hardware for sensors, and an Android phone.

7.2.02 Smartphone Application

The software application testing involves rigorous exercises how well certain aspects of the software work. This test required an android phone that can send and receive signals over an internet connection. Testing would begin with a basic opening of the app followed by other small tasks to make sure the application is fully operational and performs as required. This required more than one form of testing to occur to make sure that all bases are covered for the requirements of this application. The different forms of testing included:

- View functionality of what is displayed properly
- Button functionality of changing views
- Functionality of live statistics
- Button functionality of customizability
- Timing towards how fast and optimized switching views will change
- Scalability through the GUI’s response of being on different devices

The view functionality was tested by comparing the application preview with the actual application on the mobile phone. This proved to be a relatively easy task that could be conducted quickly. It was as simple as making sure the correct buttons are there in the correct layout, and that they're a proportional size towards what they are supposed to look like. The other aspect is the progress bars and if it displayed anything to begin with, if they were completely full, or if they were blank. The application needed to be able to close properly, and no crashes should result from the opening or closing of the program. The functionality stems for all available views and that means that the transition to each view should be smooth and free of crashes as well.

The button functionality for changing views was required to properly change views with a smooth transition as well as a quick-change time that made everything seem close to seamless. The program flowed smoothly and be able to move from view to view without any application crashes or large spikes of wait times from client request buildup. Although buildup could happen from other functions, simply traversing the application had no effect on the phone's speed or smoothness throughout the view changes.

Live statistics were one of the most important parts of this application. For the client to know what their plant needs or how well it's doing, the plant needed to send output to the application and the application needs to be able to receive and display it. These statistics would show up with a recent or even live version of numbers to ensure an accurate reading of the plant's environment. The application must have these numbers readily available on an opening view and be refreshable via a button. This functionality for the button needed to be tested to work the same as a refresh page web browser button. The numbers should blank out for a few moments while the statistics are refreshed. These small details needed to be reassured to work within the GUI for efficiency purposes.

The customizability section needed to have functionality relating to the progress bars as well as other statistics such as temperature. Warnings will appear at certain levels of each extreme, and in the case of the customizability section, it should be insured that the statistics are customizable for all possible values. This is mainly regarding the water reservoir level and when exactly the client should be notified to refill the reservoir. The water level warning was set up properly that a client could input when they wanted to be notified and it should pop up when that certain threshold is obtained. This should be applicable towards other statistics as well and not just the water threshold level.

Timing involved two different aspects which included an exceptional speed towards switching views and pushing buttons as well as the smoothness between transition of views and button clicks. This was tested by comparing the time with other optimized applications, and this was counted to the nearest millisecond of view switches and button presses. The smoothness was tested based upon the human eyes and their perception. The changes of view and presses were choppy or jagged in anyway.

Scalability was another crucial aspect in putting an application on the market. The GUI had to not only work for the device being tested upon, but other devices as well. The main topic of discussion is other screen sizes and less related to different brands of phone. The screen's images needed to fit the screen and not be condensed into the same screen size of the original device it was created upon. This stretches towards button sizes as well. They would not remain small or larger than necessary. The buttons needed to be pressable and should not have crowded the screen.

7.3 Demonstration Plan

This section will detail how the team planned to present the finalized project at the end of Senior Design II this upcoming fall semester. This gives a brief run-down and summary of the project we chose that will include the reasons why we took it upon ourselves to construct our design, our goals, and a quick list of components. The components include the following:

- ESP8266 Wi-Fi-module / microcontroller
- Moisture level sensor
- pH level sensor
- Water level sensor
- Light intensity sensor
- How all sensors interact with the ESP8266
- How all data is used in our accompanying smart phone application
- Water pump design
- AC/DC power supply and we chose this over a battery pack

After all component details had successfully illustrated, we planned to demonstrate the physical device. The sleek, elegant design and the ease of use to take care of your favorite household plants. Then we would continue to talk about how data from the sensors is utilized. Some talking points would be the following:

- How the microcontroller is initialized and important variables that are used for demonstration and typical normal use cases
- The setup of a serial communication channel between the microcontroller and all sensors attached to it
- Explain the order and how frequency data is pulled from these sensors. Mentioning any computations in use to gain accurate values
- Explain how the final values are stored and then sent over a wireless signal through the ESP8266 module to the smartphone application

From here we switch over from hardware and begin showcasing the software application. The basic home screen would be first seen by a user that would be shown which will show data from the moisture sensor, pH sensor, light intensity of our LEDs, and the water level of our reservoir that has been received wirelessly from the ESP8266 module. We showcased the manual overwrite function of watering the plants and taking control of our lighting system as well.

Once the smart phone application had proven to be functional, we would explain the basic time frame outline of when we pull data from our sensors and why we chose certain time intervals for various tasks. If this is in fact the case, we would be sure to point out the actual time intervals and why we chose these specific time intervals. This concluded the software presentation for our project design.

This brought us to the end of our presentation. The conclusion would feature talking points that include the following:

- Any complications, bugs, or errors we are aware of
- Advantages and disadvantages of our product compared to other similar products
- Features we were wanting to add but could not and the accompanying reasons why

At this time the presentation would be completed and we would begin to field questions from our chosen board of professors.

8. Administrative Content

When working on a group or team assignment is important to track deadlines and mark tasks once completed. It is also important to meet regularly to discuss progress, make lists of tasks to be accomplished, and go over any issues that a team member is facing. Being on top of due dates and completing our goals before deadlines are due would help give us time to review each other's work and make any necessary corrections. The team needed to keep each other in mind when finalizing a plan and develop an integrated plan that helps all members be successful in their tasks.

This section features and goes over the following:

- All due dates of assignments, their status, and who is responsible for the subject
- How the cost is to be divided between team members given the costs of components

8.1 Milestones

In this section we will be discussing the milestones of this project. The milestones are going to be split into two section, first section is for senior design 1 and the second section is for senior design 2. These milestones ensure time management within each member of the group. Having a start and end date allows us to gage what time we need for research as well as group time, application time and writing time. Being that each member has their own schedule at times it is difficult to meet with each other or the professor, so putting these milestones in place allows us to make time within our daily schedules for the things that are needed to be completed for the project. In addition to that the milestones allows us to hold each other accountable for due dates and keeps the group on the same page. Having these milestones in place also allows for group discussions to be on track with the project ensuring we don't get off topic and making the best use for our time. All in all, having the milestones in place ensures the group efficiency and effectiveness when completing the senior design process. The two tables below (Table 8.1 and Table 8.2) display the relative milestones for each section of the Senior Design class.

Table 8. 1: Senior Design 1 Milestones

Senior Design Process	Start	End	Due Date	Complete
Senior Design Ideas	5/14/19	5/16/17	5/21/19	100%
Initial Project Documentation	5/21/19	5/25/17	5/27/19	100%
Meeting with Professor	5/30/19	5/30/19	5/30/19	100%
Divide and Conquer 2.0	5/30/19	6/7/19	6/7/19	100%
Table of Contents	5/30/19	6/13/19	6/14/19	100%
Microcontroller Research	5/30/19	6/8/19	7/1/19	100%
Sensor Research	5/30/19	6/28/19	7/1/19	100%
Water Pump Research	5/30/19	6/28/19	7/1/19	100%
LCD Screen Research	5/30/19	6/25/19	7/1/19	100%
Android Application Research	5/30/19	6/7/19	7/1/19	100%
Programming Language Research	5/30/19	6/19/19	7/1/19	100%

WIFI Module Research	5/30/19	6/24/19	7/1/19	100%
Growth Plant Lights	5/30/19	6/7/19	6/7/19	100%
60 page Completed	5/30/19	7/6/19	7/7/19	100%
90 page Completed	5/30/19	7/21/19	7/21/19	100%
120 page Completed	5/30/19	8/1/19	8/2/19	100%

Table 8. 2: Senior Design 2 Milestones

Final Design Process	Start	End	Due Date	Complete
Ordering Components	7/30/19	10/20/19	10/29/19	100%
Breadboard Testing	9/1/19	11/15/19	11/15/19	100%
PCB Design	8/26/19	10/29/19	10/29/19	100%
Build Prototype	9/1/19	10/12/19	10/15/19	100%
Testing Prototype	9/1/19	10/15/19	10/16/19	100%
Final Documentation	9/14/19	11/20/19	12/2/19	100%
Finalize Project	10/29/19	11/20/19	11/22/19	100%

8.2 Budget and Finance Discussion

Table 8.3, pictured below, shows the budget for the project designated. The costs are more of an estimated projection as to the reasoning of this project has not been started yet. The total is a rough estimate as well towards the overall cost of the parts needed and required. This does not entail other unforeseen costs that can arise such as malfunctioning of parts during prototyping as well as the failure of the system. This means that the major parts procured such as the light fixture will work throughout all testing and not require a replacement.

Table 8. 3 – Group Budget

Design Components	Price
Light Fixture	$50.00
Woodworking Supplies	$40.00
Voltage Regulator	$40.00
Microcontroller	$40.00
Water Pump	$16.00
Water Reservoir	$19.00
Tubing for Water Reservoir	$20.00
Soil Moisture Sensor	$15.00
PH Soil Sensor	$20.00
Temperature and Humidity Sensor	$10.00
WIFI Module	$14.00
Circuit Components	$50.00
Light Intensity Sensor	$10.00
Total	$360.00

8.2.01 Estimated Cost of Device

The beginning cost of this project is designed to be around $200 for all components including random circuit components such as resistors, capacitors, and diodes. This price however is not all-encompassing of possible part malfunctions. If a part fails and needs to be replaced, then that price for the new part has not been incorporated into the final cost. This might require further money to be spent to ensure that the project is finished and complete without any types of damaged parts.

The total cost is a baseline minimum for what the cost could be of this project. There could be unexpected expenses along the way such as more required parts or malfunctioning parts. The money required will be around $200 and if every part where to fail it would be closer to a $300 - $400 range. Additional parts could be required for testing and prototyping, but more than likely the major parts will work all the way through the project. In the case of failure another price has been calculated to overcome this obstacle.

8.2.02 Funding

The project's cost was funded by all group members. The total was calculated and equally split among four people. No sponsor was acquired for this project and it was entirely funded by the group. The total cost is projected to be around $200 which means that each group member would contribute close to $50. The group decided on this from the start that a total price would be found and divided equally among everyone. The parts were mostly procured by one person, and from these purchases the prices were saved and totaled to be evenly divided among all the other group members. This is how the one group member would be reimbursed for their contribution towards acquiring all the required parts for the project.

9. Stretch Goals

This section will go over what we like to call 'stretch goals. We will define stretch goals as functions of our project that we would like to add to or advance the functionality of granted that we complete and have a working overall unit within the allotted time frame.

9.1 Extra Features

As described above, we now discuss extra functions and/or features we either:

- Would like to add to the project once we have a base working product
- Features we were not able to add into the project due to the time constraints and/or other restricting conditions.

Some additional features include the following:

- Voice integration
- Pre-programmed plant configurations
- Manual override of water pump/lighting

Voice Integration

One feature that we would love to include into our design is to integrate voice functionality into our smartphone application. With smart home appliances dominating the market in today's world, voice control is at the top of the features. More and more people are getting used to communicating with their household appliances and pocket phones more than ever before. It has become normal to ask your phone 'Hey Siri', or 'Ok Google'. As a team we feel this feature would be incredibly useful in our 'Plant Nanny' self-automated caretaker of plants project. A short example of how a user may use the voice command feature is demonstrated in the figure below (Figure 9.1).

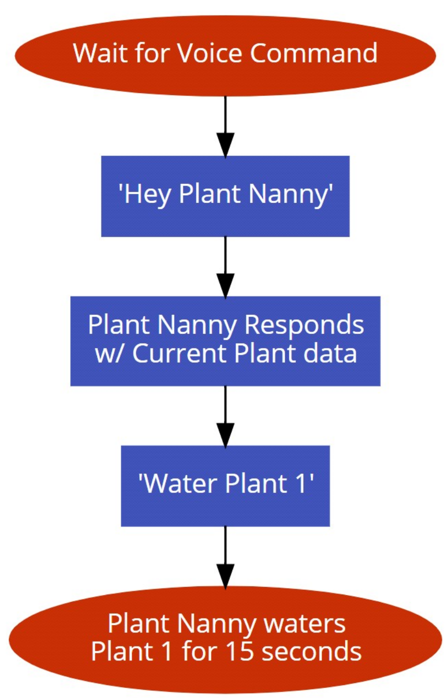


Figure 9. 1: Voice Command Demonstration

Pre-programmed Plant Configurations

An additional feature we would like to add to our senior design project are pre-programmed plants on the software side of design. Using known coding practices, the team would configure optimal settings for some popular and known indoor plant species. Having this feature would greatly benefit a user of our product if they are a plant enthusiast who commonly keeps small and popular house plants inside of their home. Below you will find a list of some common plant types we are considering pre-programming into our design project:

- Basil
- Parsley
- Mint
- Dill
- Sage
- Rosemary
- Thyme
- Cilantro
- Aloe Vera
- Snake Plant
- Lavender
- Chives
- Oregano

All these plants could easily be pre-configured into our software and smartphone application to ease the user in selecting which plants he or she wishes to care for and would not take a considerable amount of time or difficulty.

Manual / Intensity Override

An important function we feel should be included assuming proper time management and design time allows to, is to allow the user complete override control of all the basic features of our product. This is important because the user may feel the 'Plant Nanny' is not watering their indoor household plant enough or often enough. Should they feel this way, they should be able to manually control the water pump system and also the lighting system.

Overriding the water pump would be with a simple option featured in our smartphone application. The user would select 'override' and be presented with an on and off button. When the user pushes the 'on' button, the water pump would turn on for the selected plant. It would follow that the water pump would then turn off when the user selects the 'off' button.

The intensity override function we would like to incorporate into our design is in relation to our lighting system that we have designed to provide a valuable light source to the plants in question. When the override function is enabled, the user will be presented with several options to control the provided light source. Those options include:

- On/off functionality
- Intensity
- Time duration

The on/off functions would simply turn the light source on or off depending on the users' preference. The intensity option would allow the user to enter a percentage varying from 0% - 100%. We feel this option would allow the user to independently decide how much light the plant got. If desired the user could simulate the sunlight from outside with an indoor light. Lastly, the time duration function would allow the user to set a time duration that the light should stay on. If the user only wishes to have a light source on his or her plants for 6 hours, we feel the user should be able to make that choice.

10.0 Conclusion

All the research, designing, planning, and effort of the self-care plant project known as the Plant Nanny was a large task that required time, effort, and attention to detail. It is a multi-faceted problem that required specialization in multiple fields of study. It seemed like a large task with only four people and such a short timeline. We had to research multiple components in and find a way for them to all communicate to each other.

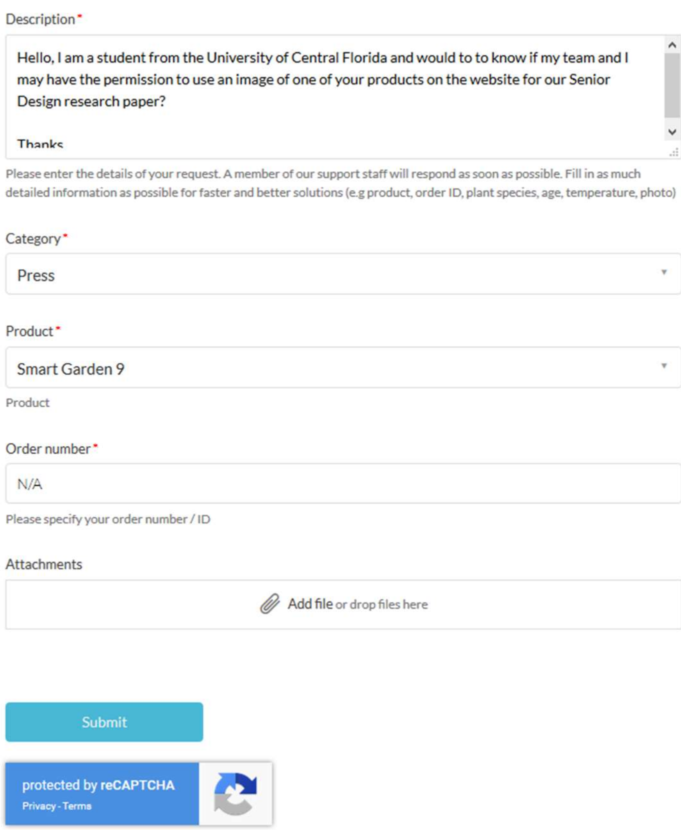
Our self-care plant design was met with tons of competition by similar products already in the market. By seeing the competition and tweaking our design in ways that met the technological needs and delivered an aesthetically appealing device, we felt our product would reign superior. Utilizing low power, and a smart selection of components that are budget friendly provided a low-cost, low-power option to many consumers who would wish to automate the care of their in-home garden.

Our end goal was to design an operational friendly self-care system that did not require the user to oversee it. A set it and forget it device that watered your plants and gave the user important information regarding their health. Home automation is the way of the future and we believe that plants should wholeheartedly be included in that aspect. This device was to be marketed towards any and all plant lovers who have a busy schedule and often forget to take care of their plants.

The Plant Nanny has proven to be a great combination of agriculture, electrical engineering, and computer science. Through the development of this project there has been worry towards the completion and perfection of the design. This however through research, design, and testing has been proven wrong through our accomplishments of this project.

Appendix A – Copyright Permissions

Figure 3.1
Permission Status: Requested


Description*

Hello, I am a student from the University of Central Florida and would to to know if my team and I may have the permission to use an image of one of your products on the website for our Senior Design research paper?

Thanks

Please enter the details of your request. A member of our support staff will respond as soon as possible. Fill in as much detailed information as possible for faster and better solutions (e.g product, order ID, plant species, age, temperature, photo)

Category*

Press

Product*

Smart Garden 9

Product

Order number*

N/A

Please specify your order number / ID

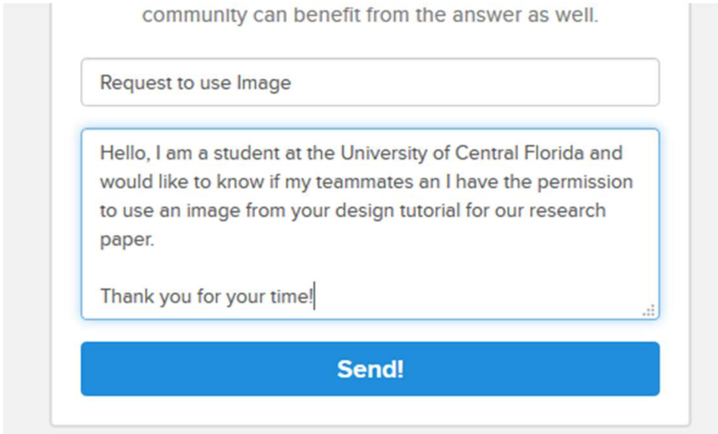
Attachments

Add file or drop files here

Submit

protected by reCAPTCHA
Privacy - Terms

Figure 3.2
Permission Status: Requested


community can benefit from the answer as well.

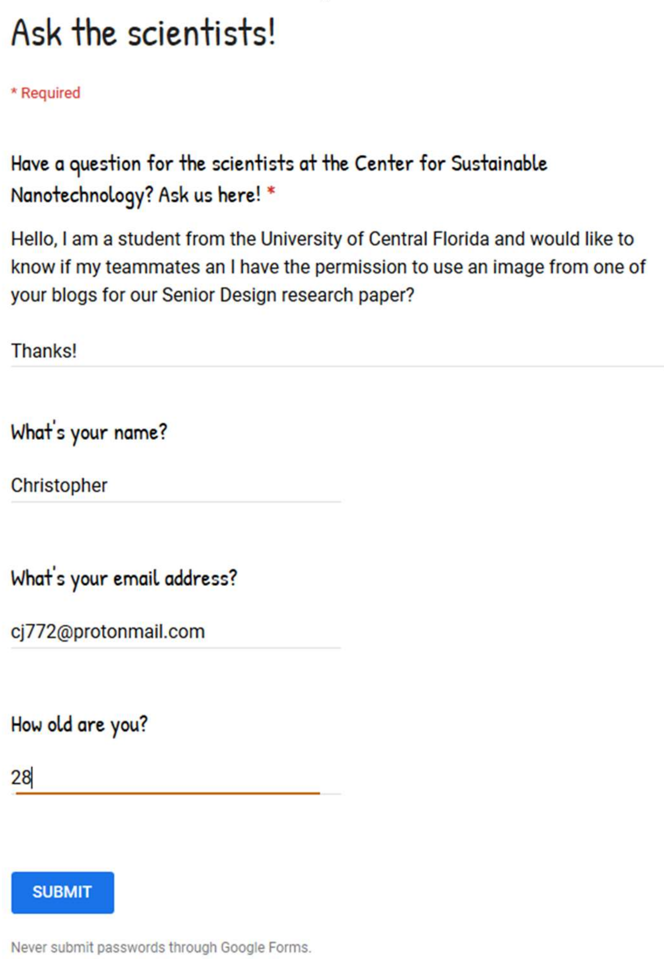
Request to use Image

Hello, I am a student at the University of Central Florida and would like to know if my teammates an I have the permission to use an image from your design tutorial for our research paper.

Thank you for your time!

Send!

Figure 3.3
Permission Status: Requested


Ask the scientists!

* Required

Have a question for the scientists at the Center for Sustainable Nanotechnology? Ask us here! *

Hello, I am a student from the University of Central Florida and would like to know if my teammates an I have the permission to use an image from one of your blogs for our Senior Design research paper?

Thanks!

What's your name?

Christopher

What's your email address?

cj772@protonmail.com

How old are you?

28

SUBMIT

Never submit passwords through Google Forms.

Figure 3.4
Permission Status: Requested

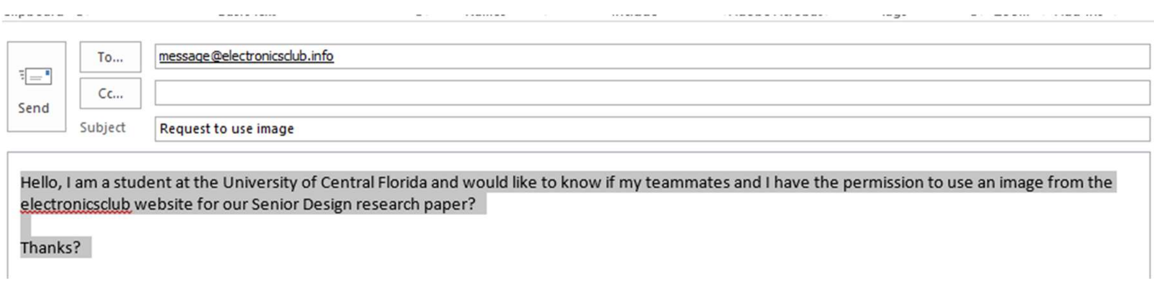


Figure 3.14
Permission Status: Requested
https://www.arrow.com/en/research-and-events/articles/crydom-solid-state-relays-vs-electromechanical-relays

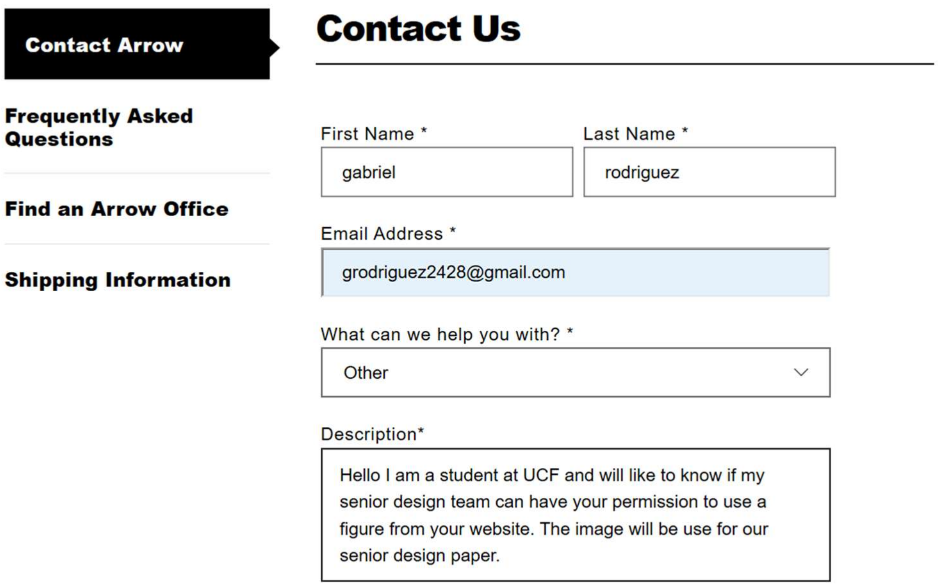


Figure 5.7
Permission Status: Requested

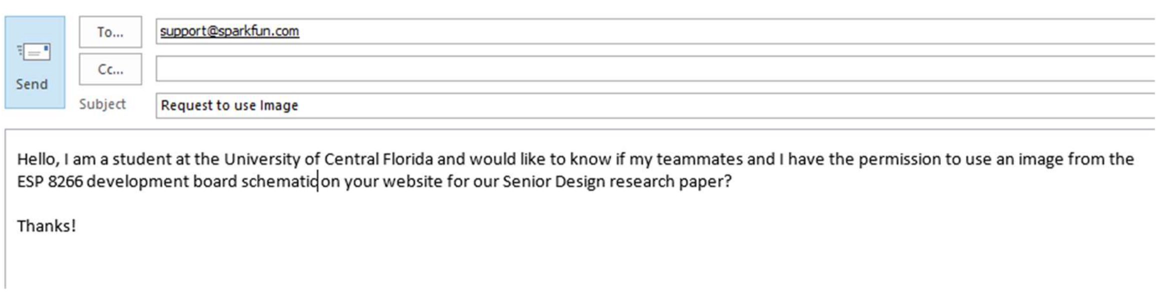


Figure 7.4: Created By Group Member

Reference 1: Soldering Safety Standards (4.1.05)
https://nepp.nasa.gov/docuploads/06AA01BA-FC7E-4094-AE829CE371A7B05D/NASA-STD-8739.3.pdf
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Use of your Soldering Standards Documentation

CS Clayton Szoke
Sun 7/21, 6:28 PM
EHSafety@stonybrook.edu

Hello,

I'm contacting this university for permission of use for your soldering safety document located at:
https://ehs.stonybrook.edu/programs/laboratory-safety/laboratory-equipment/soldering
It will be talked about briefly in my Senior Design Project for an automatic plant watering apparatus.
This project is purely educational and will not be marketed in any form. Please let me know if this acceptable to use. Thank you.

Best Regards,
Clayton Szoke
University of Central Florida

Reference 2: Soldering Safety Standards (4.1.05)
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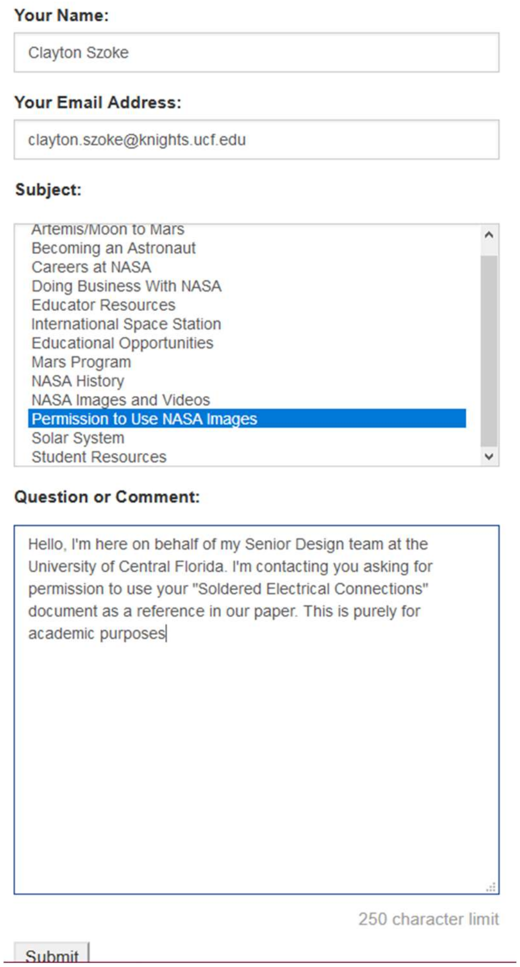

Your Name:

Clayton Szoke

Your Email Address:

clayton.szoke@knights.ucf.edu

Subject:

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Reply all

Hello,

I'm a student at the University of Central Florida. I'm asking for permission on behalf of my Senior Design team to use this document in our report. It would be used for purely educational purposes. Thank you in advance.

Best Regards,
Clayton Szoke

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