UNIVERSITY OF CENTRAL FLORIDA

SENIOR DESIGN 1

GROUP 9

LeafAlone Hydroponics System

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Contents

List of Figures

List of Tables

Executive Summary

The fields of chemistry have merged with biology in the last few decades in a way that has never been seen before. Humanity is only just now discovering precisely the way that plants absorb nutrients and how it helps them to grow, and hydroponic methods are the unintended miracle that have resulted from this research.

The barrier to fully realizing the miracle of hydroponic plant growth is a myriad of inconveniences and expenses that no one is willing to put up with, even given the dramatic improvement in plant growth and product yield. There is an enormous trend in the educated populations around the world to develop sustainable and environmentally friendly technology, and this cloud of confusion and inconvenience is holding hydroponics true potential back.

The moment of opportunity has been identified, and this personal hydroponic system is the answer to all both the problems of inconvenience, cost, and prerequisite knowledge. Offered in this design document is a hardware device that completely compartmentalizes home grown hydroponics system into an easy to use and energy independent plant grower, combined with a software service that allows the people growing their plants to have personal access to their plants health at all times on a website.

The hydroponics market is still a small and niche one, and there are few competitors that are offering a reasonable device that contends with this hydroponic solution. But, there are brick and mortar stores popping up in every major city in the world because this is a market that is growing and is completely on trend. This teams competitive advantage to the other major companies is that the margins of profitability are simply too high, and the technological barrier has prevented others from intruding into this space. This team of electrical and computer engineers is fully up to the task of creating a high quality product for this task.

Chapter 1

Product Description

Hydroponic gardening is a great way to grow plants to their full potential. Plants are given as much nutrients and water as they can absorb. In the past, setting up a hydroponic system required research, many installation steps, and daily monitoring to ensure proper growing conditions.

This chapter contains:

1. An introduction to the members of the team developing this project, as well as contact information.
2. The motivation behind the design and development of this project, and why the team has made the decision to build this particular device.
3. The overall goals and objectives that this hydroponics system satisfies.

1.1 Member Identification

Shown below in Table 1.1 is a list of the members involved in this hydroponics project design. This project's team consists of electrical and computer engineering students at University of Central Florida in the capstone senior design class.

Name	**PID**	**Email**
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Table 1.1: List of Member Names and Contact Information.

1.2 Motivation

Hydroponic gardening is a great way to grow plants to their full potential. Plants are given as much nutrients and water as they can absorb. In the past, setting up a hydroponic system required research, many installation steps, and daily monitoring to ensure proper growing conditions.

Currently, implementing a hydroponic system requires research and knowledge about the type of plants to be grown. Different plants require different nutrient levels as well as a balanced water supply in terms of pH and oxygen content. Once this information is known, a gardener must choose a hydroponic design and set it up correctly. This process can take anywhere from a day to a few weeks. A typical deep-water culture (DWC) hydroponic design requires daily pH, nutrient level, water level, and temperature testing. For the average gardener with a busy lifestyle, this amount of research, initial labor, and maintenance is deterring. At the moment, most gardeners find growing in soil to be less strenuous and easier than hydroponic gardening.

The motivation for this senior design project is to create a DWC hydroponic system that allows anyone to have the ability to farm their own hydroponic plants using a simple automated system. This system will relieve the user from a lengthy setup and daily maintenance. The user will be able specify the plants wanting to be grown through a web interface which is connected to the microcontroller running the system. The plant specific settings will be loaded and thresholds for each sensor calibrated into the microcontroller, thus eliminating any research the user needs to do on their own. This system will perform all daily testing necessary, adjust system levels (pH, nutrients, water) as necessary, notify the user of a problem requiring action, and log all testing data for analysis.

This design will include sensors, a power supply, at least one microcontroller, and a web interface for users to monitor sensor data. Project group members consist of three electrical engineering students and one computer engineering student. This dynamic design will provide a sufficient amount of work for each individual and will challenge each member to put the skills learned in college to the test.

1.3 Goals and Objectives

The main goals for this project are to create an automated system that lets anyone have the ability to farm their own hydroponic plants in their backyard. The system shall also be able to power all of the electrical components with solar power, so that it could be used in places where electricity is not easily supplied. The system shall require low maintenance and produce better results than traditional soil based farming techniques. The system as a whole shall be durable and weather resistant. Each sensor shall interface with the main microcontroller and be easily applied to different hydroponics buckets as a function of portability. In the event that user action is required, the user shall be notified via text message or email.

Power Supply - The power for this hydroponics system is generated by solar panels or alternatively can be plugged into standard wall AC power wall outlets. Similar hydroponics systems have used 20W of generation with solar cells. A 12V battery will store power so that the microcontroller can access a steady power supply, even when the panels are not exposed to the sun. The system will run for at least a day when the battery is fully charged. Certain functions of the system might toggle on and off periodically based on the available power. This logic will be managed by the microcontroller.

Control - In order to analyze the data coming from the sensors, they need to be passed to a microcontroller. This microcontroller will receive data from sensors, analyze the data, and send the data through a Wi-Fi connection to a web server where the data will be analyzed and displayed. It will also make decisions about when to add nutrients based on the sensor measurements. Statistics about the plant growth will be sent over the communications system to a companion website for the user to view.

Communications - There is a real time link between the microcontroller and the connected web server, and this is facilitated by a Wi-Fi adapter that allows the controller to talk to other devices. A connection to the web server allows the user to receive data from the microcontroller and displays graphs from this communication.

Sensors - Many different sensors will need to be included and interfaced with the microcontroller. Many properties of the water need to be measured to make sure that the plant will grow in an optimal environment. The pH level, Electrical Conductivity (EC), water level, and temperature of the water can all be measured with electronic sensors. Electronic liquid dispensing pumps will be used to adjust pH and nutrient levels as needed. A camera is included to provide pictures of the plants stages of growth, and a photosensitive sensor will determine the system's exposure to the sun.

Hardware - The hardware of the system consists of a containment system for the growth environment, and an air pump and filter combo that will be used to clean and add oxygen to the water. The pump and nutrient containers are connected and driven to the microcontroller, which determines when the systems need to operate.

Software - The system will have a companion website for which will allow the user to change configuration options of their system. The website will also display information about the plants growth in the form of graphs. The user will also be able to look at the progression of their plant through pictures that the camera on the unit takes, like a time-lapse video.

1.4 Product Requirements and Specifications

Table 1.2 shows the current design specifications for this hydroponics system. The specifications have been used as a way to properly design the system, and add constraints to the materials and devices will be purchased.

Attribute	**Value**
Battery Life Without Charge	24 hours
Number of Plants	2
Weight (Empty)	Approx. 20lbs.
Dimensions	30" x 20" x 14"
Total Lifespan	6 months
Operating Temperature	10 - 35°C
Water Consumption	1-15 liters per day
Reservoir Volume	75 L
Working Temperature	10-40 °C
Sensor Measurements	25 minutes intermittently
Electrical Conductivity Range	0 to 20,000µm cm^{-1}
pH Sensor Range	0-14 pH
Temperature Sensor Range	10-35°C
Liquid Dispenser Flow	10-50mL min^{-1}
Air Pump Flow	500-1000mL min^{-1}
Enclosure Sealing	Rain proof
Battery Capacity	20Ah
Operating Voltage	12V
Solar Panel Power Output	20W
Communications	Wi-Fi
Data Rate	6-54Mbps
Maximum Signal Power	15dBm
Microprocessor Size	8bit
Microprocessor Speed	16MHz

Table 1.2: Hydroponic System Specifications

Chapter 2

Research Related to Product Definition

Here, research is done in order to look at ways that the product can be designed so that it matches the goals and specifications. Different methods of accomplishing these goals are compared against each other until a decision is made on the method that will be used in the design.

Topics that are discussed in this section include:

1. An initiation to different techniques that are currently used in the field of hydroponics.
2. A look at some similar commercial products or other similar senior design projects.
3. Research about major subsystems that might be included in the project.
4. A device exploration that looks at multiple devices that might fit one of this projects objectives and specifications.

2.1 Hydroponics Science and Methods

Hydroponics systems provide an alternative way to grow plants rather than soil based gardening. The essentials needed for plant survival and growth are sunlight, water, nutrients, and oxygen. Hydroponic plants are grown in different mediums (i.e. not soil) while a water based nutrient solution and oxygen are delivered to them in different ways. Common hydroponic mediums are Hydroton rocks, which resemble small clay pebbles, and Rockwool, which has a similar consistency as compressed cotton balls. Along with a plastic mesh basket that holds the medium, the main purpose of both the basket and medium is to provide plant stability during growth. While soil based plants use their medium for nutrients and stability, hydroponic based mediums provide no nutrients. The plants roots grow through these mediums and are exposed to the nutrients and oxygen they need using different techniques. For this project, research and analysis was done on common hydroponic techniques that are as simple as possible to implement while still being effective. Two techniques explored were ebb and flow (E& F) and deep water culture (DWC).

2.1.1 Deep Water Culture

A deep water culture design has a very simplistic setup. Plants lie in a plastic mesh basket that contains the growing medium. The plants roots grow through the mesh basket and into an oxygen and nutrient rich reservoir. The reservoir contains a water based nutrient solution. Using an air pump and attaching hose, an air-stone is placed at the bottom of the reservoir to provide constant oxygen into the solution. This air pump runs constantly for multiple reasons. First, to ensure proper plant growth, plant roots need oxygen at all times. Second, the continuous flow of oxygen deters bacteria growth in the reservoir that can lead to root rot and eventually plant death. Each basket is located on the top of the reservoir. As the roots grow into the solution, the plants are able to intake as much nutrients and oxygen that they need. Figure 2.1 below illustrates the basic design.

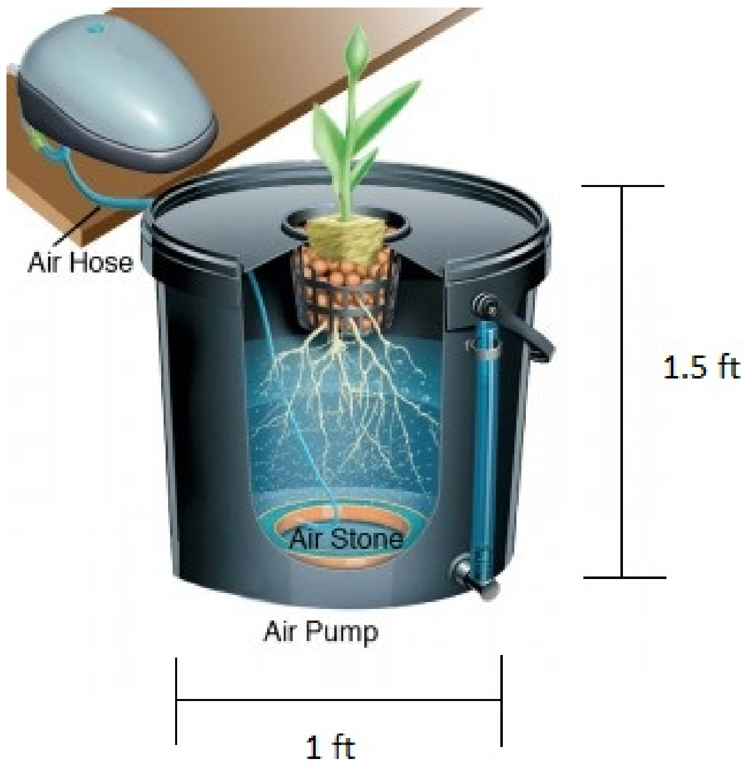

Figure 2.1: Example Deep Water Culture Design - *Reprinted with permission from Sunny Datko*

2.1.2 Ebb and Flow

The basics of an ebb and flow design are very similar to the ebb and flow of tides. A nutrient rich solution is periodically flooded into a grow tray containing the plants and roots. The solution then drains back out into a holding reservoir. Plants lie in plastic mesh baskets that hold the growing medium. The plants roots grow through the medium and protrude out the bottom of the mesh baskets. All of the baskets lie in a grow tray with room underneath each basket for a nutrient solution. Different growing mediums retain different amounts of water over time. Because of this, the frequency of flooding is determined by the medium used. A timer is used to control the flooding cycles. A flooding cycle begins with a nutrient rich reservoir located underneath the grow tray. A water pump in the reservoir then pumps the solution into the grow tray above. During this pumping, the roots and medium are exposed to the nutrient solution. The solution stays in the grow tray for only a few minutes before the pump is then turned off. The solution then flows back into the reservoir tank by gravity. The growing medium is now moist and provides the roots with water and nutrients. During the draining cycle, new oxygen is filled in the grow tray giving the roots plenty to intake. The basic flow of this technique is represented in Figure 2.2 shown below.

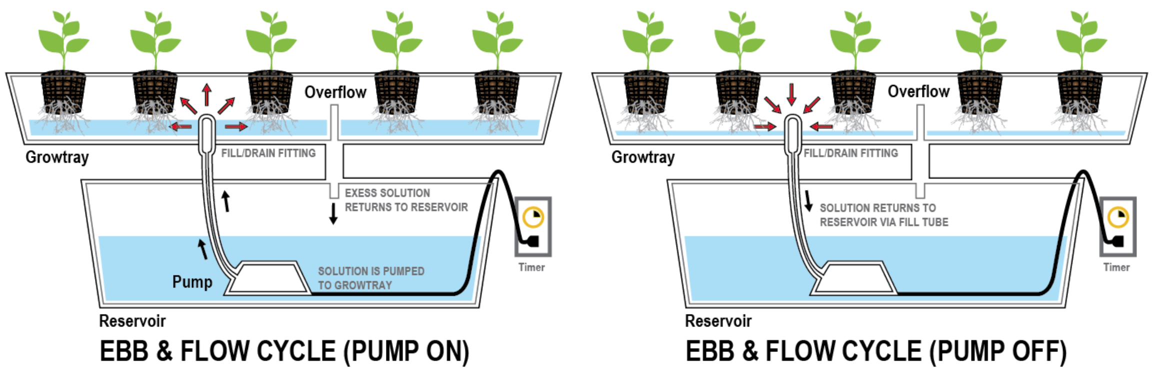

Figure 2.2: Example Ebb and Flow Hydroponics System - *Reprinted with permission from Sunny Datko*

2.1.3 Pests and Bacteria

When growing, pests and bacteria can significantly affect the health of the plants. All plants grown outdoors are subject to environmental predators that can cause harm. For hydroponically grown plants, these nuisances can be divided into two main locations: external to the system, and internal to the system.

Factors external to a hydroponic system are those that affect the plant outside of the growing system and above the root level. These factors apply for soil based plants as well. The problem that plants can encounter is pests. Aphids, mites, spiders, ants, and caterpillars are the most common in tropical environments. An important part of having successful plants is recognition of a pest. Most pests can be identified by physically examining the plant. Looking at the underside of the leaves is the most important place. Once a pest has been found, they can be dealt with swiftly. Gardening stores sell simple pesticides that kill the most common pests. As a preventative, periodic plant examination and/or spraying of a pesticide can highly reduce the chance of infestation.

Factors internal to a hydroponic system affect the plants at the root and reservoir level. The most common problems experienced by hydroponic gardeners are bacteria growth and algae. In a hydroponic system, bacteria growth can stunt plant growth, kill roots, and cause death. Most bacteria growth is cause by bad growing conditions. Insufficient oxygen supply along with high temperatures in a water rich environment will expedite the growth of bacteria. Algae growth is caused by exposure to light. Hydroponic systems need to be closed and sealed from light to ensure no algae growth. Looking at the plant reservoir or roots, one can identify signs of a bacteria or algae problem. A common sign of algae growth is a mucus like substance found on the roots. This substance can range in color from clear to green and is a positive indicator of algae growth. Bacteria is harder to identity but can be spotted by plant roots turning darn brown and starting to rot. Once bacteria or algae has been found, the reservoir must be cleaned thoroughly and plant roots sprayed down to remove any bacteria.

There are several approaches to inhibit the growth of bacteria and algae. One method is to add hydrogen peroxide to the nutrient solution. This method will kill all bacteria and add more oxygen in the solution. The negative side to this approach is that the hydrogen peroxide also kills any beneficial bacteria used by the plants. A more common approach is to add beneficial bacteria during the initial hydroponic setup that stimulates root growth while providing a defense against harmful bacteria and algae. Bacteria composed from poultry litter are commonly used in products sold for this purpose.

2.2 Existing Similar Projects and Products

Here are some systems found commercially that approximate the goals and specifications of this hydroponics project, and can be used for guidance by looking at the design choices that these companies have made.

Sustainable Microfarms Hydroponics Genesis Controller - Another project to look at, The Sustainable Microfarms Hydroponics Genesis Controller, is found on the website Indiegogo that comes in an easy to use unit that can control the pH and nutrient level of the water used in your hydroponic grow bucket. Indiegogo is a website where people can receive funding in the form of donations for any type of project they want start. For this project, you have the option to pay $600.00 to receive the Genesis Controller that regulates the pH and nutrient levels or you can pay $1800.00 and you receive the Genesis Controller along with the reservoir box and materials for growing the plants. The unit has a small LCD screen located on the top of the unit where the user can easily change the settings of the Genesis Controller with 4 buttons. It dispenses acids and bases to stabilize the pH along with liquid nutrients to keep the plants healthy and comes in a small and simple clear plastic unit. This product will keep the plants growing in a hydroponics growing environment without the grower needing to constantly check the pH level or add nutrients to the water.

GroBot Evolution - The GroBot Evolution is a single unit growing product that contains a multitude of sensors that take data for pH, nutrient level, CO2 level, water level, air and water temperature for the hydroponics growing station or room. The data collected is used to keep the growing conditions constant with respect to the user's desired settings. Additionally, the data is displayed for the horticulturist conveniently on a web application that can downloaded onto an android phone. The GroBot is not intended to be a complete hydroponics system but instead can be added to a hydroponics system that is already set up in which the GroBot is used to maintain all of the necessary environment factors of the growing system.

The Green Automation - The Green Automation is a prototype hydroponics system that uses an Arduino development board and LCD screen to program the settings for the system. This project was only partially completed but it gives some interesting ideas about possible interfacing for the system. The final product is a small enclosure with a touch screen interface on the front of the unit. A touch screen is an effective and easy-to-use user interface for varying the pH and nutrient level as well as monitoring the temperature, light, and humidity for the hydroponic growing environment.

2.3 Communication Technologies

In order to better elaborate on the necessity of communications technology which should be involved in the design, the first question that needs to be answered is: "Why communicate?". This design needs such an implementation because, as it often occurs with smart systems, an engineered method needs to be facilitated for the end user to monitor their hydroponic system's most recent sensor readings, and to take the proper action when it is needed to prevent a sudden calamity which could cause the whole plant to die.

This hydroponics system is intended to work in facilities which could range from small areas like a person's back yard, or large areas as big as a farm that can maintain multiple hydroponic systems. In both cases, it is assumed that the user has a prepared wireless communication system in order to have access to all of their hydroponic systems sensor readings and profile information in real time.

The two technologies which have been researched to serve this purpose are Bluetooth, and Wi-Fi networking solutions. Either one of these would serve as a communications bridge from the microcontroller main board to the web server platform where it can be stored, analyzed, and displayed on an easy to use website or application for the end user. The user is able to monitor their hydroponic plant's statistical measurements in this web page. These statistics represent the actual measurements for pH level, nutrition level, power level and water level.

2.3.1 Bluetooth

Bluetooth technology or Wireless Personal Area Networks (WPAN), is a wireless communications method meant for exchanging information over short distances using short wavelength UHF radio waves. Bluetooth is also known by its operation architecture defined in IEEE 802.15.1. It operates in the unlicensed 2.4 GHz ISM band and its fundamental purpose of operation is to connect devices like mobile phones and laptop computers, which are not long distances between each other. Bluetooth supports either a point-to-point connection as well as point-to-multipoint ones.

This microcontroller is to send its data, which is collected from sensors, and then processed straight to the network server. This network server analyzes this data and displays it for the end user on a web page. In order to achieve this goal, a communications bridge could be used between the microcontroller of the hydroponic system and the users device. The users device, such as a phone or laptop, is something that has been assumed to be a prerequisite for the user to own prior to obtaining this hydroponic system.

The Bluetooth technology in this aspect will work as an accessing tool for the micro-controller to gain an access to the user's device. It is assumed that the user network exhibits Bluetooth Class 3 radios which normally offers a range of up to 1 meter.

2.3.2 Wi-Fi

Before venturing too far into how Wi-Fi works and its basic functions, important terminologies must be defined which will play a big role in the further discussion of the Wi-Fi implementation itself.

RF Transceiver - RF Transceivers are the key building blocks which are needed to make an integrated transceiver for wireless and cellular operations. Being a transceiver indicates that the device includes both a transmitter and a receiver module. It contains low-noise amplifiers, mixers, voltage controlled oscillators, RF power amplifiers, and phase-locked loop systems.

IEEE 802.11 and WLAN - Wireless Local Area Network (WLAN) is a data transmission system which has ability to provide data access to multiple devices in a local area. It uses high frequency radio waves for communications on the unlicensed FCC frequency bands. The 802.11 is a digital communications module which is created and maintained by IEEE LAN/MAN standards committee. IEEE 802.11 module is comprised of media access control layer or (MAC) and physical layer specifications. Both of these layers represent the last two layers of the Open System Interconnect (OSI) model layers which sets the necessary protocols for systems to talk with each other. The 802.11 module represents the method of making 802.11 enabled devices to communicate with each other wirelessly.

The diagram shown in Figure 2.3 shows the first two OSI layers which represents the place where IEEE 802.11 operates from to setup a wireless connections. Layer number two, or the data link layer, sets up the method of assigning the MAC address and performs data stream encapsulation operations or framing. Communication bridges maintained between IEEE 802.11 enabled computers or devices could take on several frequency bands. Some of these bands are like 2.4, 3.6, or 60 gigahertz. The 802.11 family consist of a series of half duplex over-the-air modulation techniques which use the fundamental protocol.

Just like Bluetooth technology, Wi-Fi (or WLAN) is a digital communication technology which facilitates a data communication method between Wi-Fi enabled devices and a Wi-Fi router. Both the router and/or the devices, should be IEEE 802.11 compatible to be able to talk with each other. The purpose to using such a network is to allow users to use the resources that are connected to the network (file sharing, printing,..etc), and

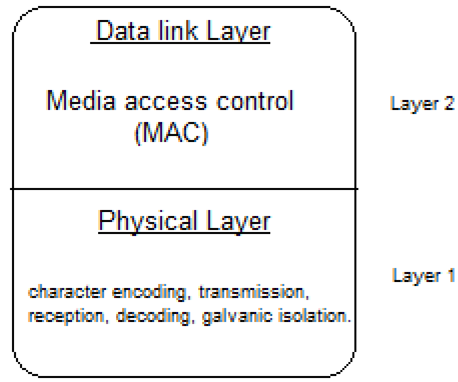

Figure 2.3: The First Two Layers of the Open System Interconnect Model

access the internet at the same time. Wi-Fi wireless technology works in a frequency range between 2.4 Ghz and 5 Ghz depending on the mode in which it is operating. The latest standard mode used is IEEE 802.11N, which uses 5 Ghz frequency and has data transfer speeds of around 140 Mbps.

Wi-Fi Antenna - The Wi-Fi antenna works by sending radio transmissions on specific frequencies where listening devices can receive them. It is an electrical device which converts an electrical power into radio waves and vice versa. Wi-Fi enabled devices have built-in antennas which act as key components of these radio communications with another Wi-Fi enabled device. Some Wi-Fi antennas are mounted externally on the device which can be seen on many Wi-Fi routers. Other antennas are sometimes embedded inside the device hardware enclosure.

When it comes to implementing Wi-Fi for potential users of this device, it is expected that the hydroponic system is setup in a facility which uses Wi-Fi devices which are not very far away from each other. This facility could be either backyard, or small farm.

2.4 Embedded Microprocessors and Development Kits

There are many manufacturers that can be thought of while designing this hydroponics project that essentially needs a microcontroller to control the unit. One manufacturer of microprocessors is Texas Instruments which produces many different microprocessors as well as microcontroller development boards. Some notable companies that produce microcontrollers are Intel, Freescale, Atmel, NXP Semiconductors, and Parallax. These companies all produce microcontrollers with different specifications that vary in power consumption, processor speed, and memory size.

Texas Instruments MSP430 - The first microcontroller to be analyzed for use in this project is the Texas Instrument MSP430 that can, potentially, be a great option when choosing a particular microcontroller. The MSP430 comes in ultra low power consumption varieties, which is ideal for this hydroponics project. The MSP430 microcontrollers have a maximum CPU frequency of 25 MHz and having up to 512 KB of memory storage. It also can come with a LCD controller that is helpful for certain projects, but this project does not necessarily need an LCD screen.

Texas Instruments ARM Cortex-M3 - Texas Instrument's ARM Cortex-M3 is a much faster microcontroller with more functionality than the MSP430, but this means the power consumption is also higher for this microcontroller. It comes with a maximum CPU frequency of 150 MHz and 1 MB of flash EEPROM memory for memory storage. The ARM Cortex-M3 comes with 24 PWM channels that can be used for analog outputs for powering a motor or other ac device. Serial communication for this TI microcontroller includes Inter-Integrated Circuit (I^2C), Serial Communications Interface (SCI), and Serial Peripheral Interface (SPI) with 6 UART connections as well. This microcontroller would be great in an application requiring high processing speeds and all of the flash memory that comes with it. However, this hydroponics project does not require this much computing power to be utilized, so different microcontroller options should be considered.

Atmel Atmega328 - The Arduino Uno development board by default contains an Atmel Atmega328 microprocessor, which is an 8-bit microprocessors having a 16 MHz CPU frequency. This is an 8-bit micro=controller having 32K bytes of flash memory, 2K bytes or RAM and 14 digital I/O pins. Communication with the Atmega328 is achieved with the equipped Universal Synchronous and Asynchronous Serial Receiver and Transmitter (USART), the Serial Peripheral Interface (SPI), and the Two-wire Serial Interface (TWI).

Atmel Atmega2560 - The Arduino Mega 2560 development board contains the Atmel Atmega2560 microprocessor, which is similar to the Atmega328 microprocessor in many aspects including the 16 MHz CPU frequency. The main differences between the Atmega2560 microcontroller and the Atmega328 are the device's specifications. This microcontroller contains 256 KB of programmable flash memory, 8 KB of RAM, and 54 digital I/O pins. All of these specifications are much higher than the Atmega328, which means that this Arduino microcontroller is great for a larger project that requires more I/O ports and memory for programming. Serial Communication for the Atmega2560 is the same as the Atmega328 having USART, SPI and Two-wire Serial Interface.

Atmel SAM3X8E ARM Cortex-M3 - The Arduino Due development board by default comes with the Atmel SAM3X8E ARM Cortex-M3 microprocessor, which is much different than the Atmega328 and Atmega2560 because it has a 32-bit core and an 84 MHz CPU frequency. The microcontroller has 54 digital I/O pins with 12 that are also Pulse Width Modulated (PWM) outputs and 512 KB of flash memory. It also contains 4 USARTs and 1 UART along with 2 Two-wire Interfaces (TWI), 6 Serial Peripheral Interfaces (SPI), and 1 SSC. This microcontroller might be unnecessary for the hydroponics project because it does not need that many I/O pins or the fast CPU speed.

Atmel Atmega32u4 - The Arduino Leonardo development board by default contains the Atmega32u4, which is an 8-bit microprocessor that has a 16 MHz clock frequency. This microcontroller has contained in it 20 digital I/O pins that would be sufficient for any moderately sized application. It also comes with 32 KB of flash memory for writing a program that operates the controller's function. For serial communication, it has a Serial Peripheral Interface and Two-wire Serial Interface with a USART connection as well.

Figure 2.4 shows an Atmel Atmega32u4 pin diagram to assist with the design of the printed circuit board layout in the future.

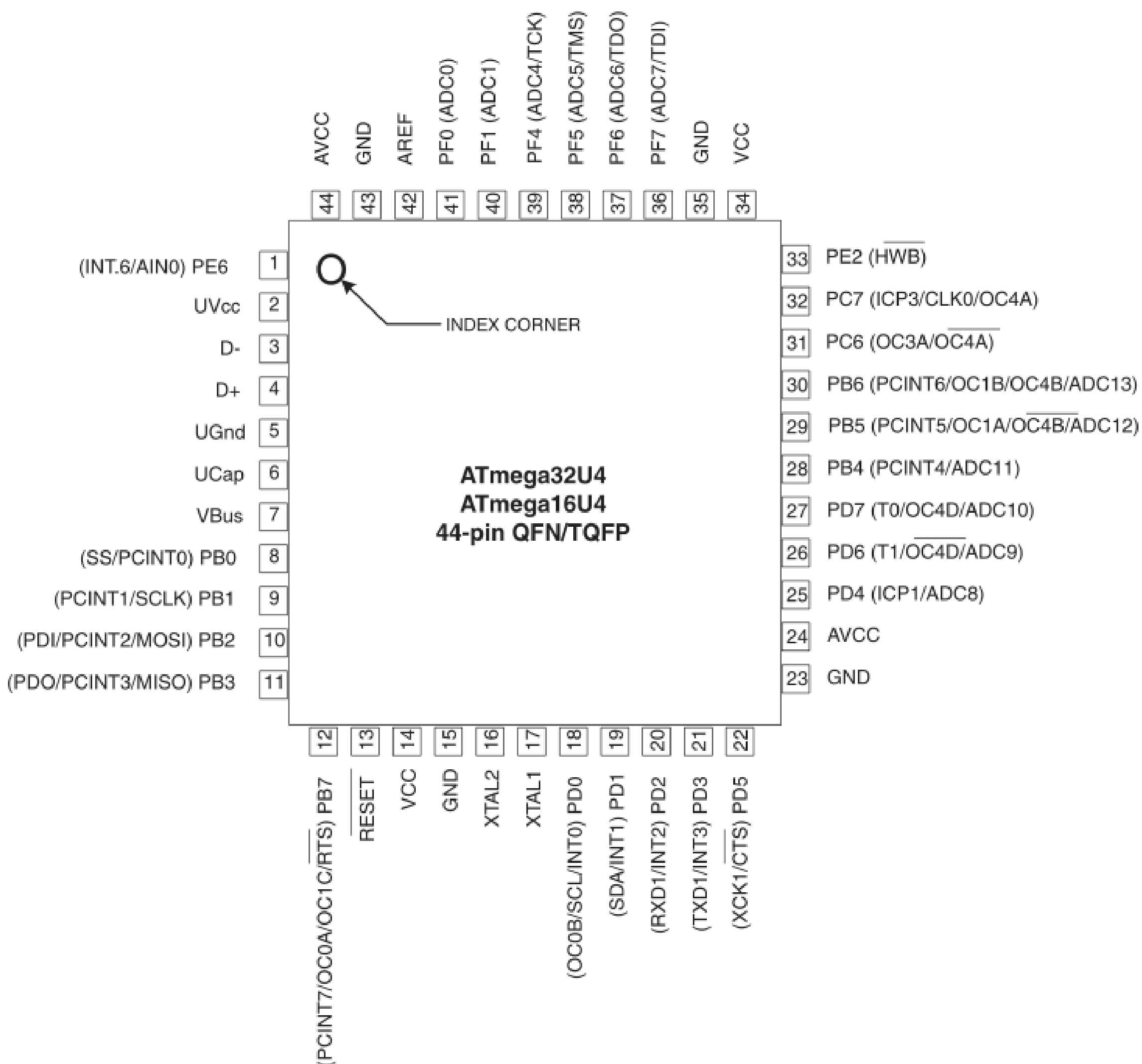

Figure 2.4: Atmel Atmega32u4 Block Diagram, *Consent to reproduce figure requested*

Additional features of the Atmel Atmega32u4 [7]:

- Advanced RISC Architecture
    - 135 powerful instructions, most single clock cycle execution.
    - 32 x 8 general purpose working registers.
    - Fully static operation.

- Up to 16MIPS throughput at 16MHz.
- On-chip 2-cycle multiplier.

- High endurance non-volatile memory segments
  - Flash - 32kbits
  - EEPROM - 1kbits
  - SRAM - 2.5kbits
- Write/erase cycles: 10,000 flash/100,000 EEPROM.
- Optional Boot Code Section with Independent Lock Bits.
- Peripheral Features
  - On-chip PLL for USB and High Speed Timer: 32 up to 96MHz operation.
  - One 8bit Timer/Counter with Separate Prescaler and Compare Mode
  - Two 16bit Timer/Counter with Separate Prescaler, Compare, and Capture Mode
  - One 10bit High-Speed Timer/Counter with PLL (64MHz) and Compare Mode
  - Four 8bit PWM Channels
  - Four PWM Channels with Programmable Resolution from 2 to 16 Bits.
  - Six PWM Channels for High Speed Operation, with Programmable Resolution from 2 to 11 Bits
  - Output Compare Modulator
  - 12 Channels, 10bit ADC (Differential Channels with Programmable Gain)
  - Programmable Serial USART with Hardware Flow Control
  - Master/Slave SPI Serial Interface
- I/O
  - All I/O combine CMOS outputs and LVTTL inputs.
  - 26 programmable I/O lines.
- Special Microcontroller features
  - Power-on Reset and Programmable Brown-out Detection
  - Internal 8 MHz Calibrated Oscillator
  - Internal Clock Prescaler & On-the-fly Clock Switching
  - External and Internal Interrupt Sources
  - Six Sleep Modes: Idle, ADC Noise Reduction, Power-save, Power-down, Standby, Extended Standby

Many of these features would work well with this hydroponics system design. It shows that the microcontroller will be able to properly interface with various types of analog or digital sensors, with some interfaces, like SPI, already built into the microprocessor.

2.4.1 Microcontroller Interfacing Methods

Interface circuits are circuits which connect between a conventional electrical circuits and the rest of the world. An example of conventional circuits could be either microcontrollers, or FPGAs, or any other kind of digital based circuits. Since the interface sits between two talking different systems, they may branch into single input single output like in a case of RS-232 protocol, or multiple inputs, single output like in the case of I^2C protocol. All of the methods considered for the design of this prototype work with digital input signals to the microcontroller.

The goal of this project to build an automated monitoring system which is capable of reading information coming from multiple hydroponic sensors (pH, nutrients, power, water level, etc.) and pass them over to the microcontroller for processing before finally sending them to the end user for review. One thing to consider is facilitating a method to interface the various sensors with the microcontroller.

RS-232 - One way to connect a sensor to the microcontroller is by using RS-232 interface. RS-232 is the standard method of connecting a Universal Asynchronous Receiver or Transmitter (UART). Each device connected to the microprocessor using this method would require the use of 2 unique digital input and output pins. The only advantage to using this method of interfacing is that it is easier to implement than the other competing methods.

In order to facilitate this idea, a single port MAX3323 chip is capable of playing a good role between the sensor along with its Analog/Digital converter, and the microcontroller itself. This method seems to be a good solution, except for the fact that it allows only one sensor to be talking to the microcontroller at a time. This configuration is shown in Figure 2.5. In this diagram, it shows a microcontroller connected with the single port RS-232 MAX3323 chip. It is really obvious that only one sensor can talk with the microcontroller at the same time using this method.

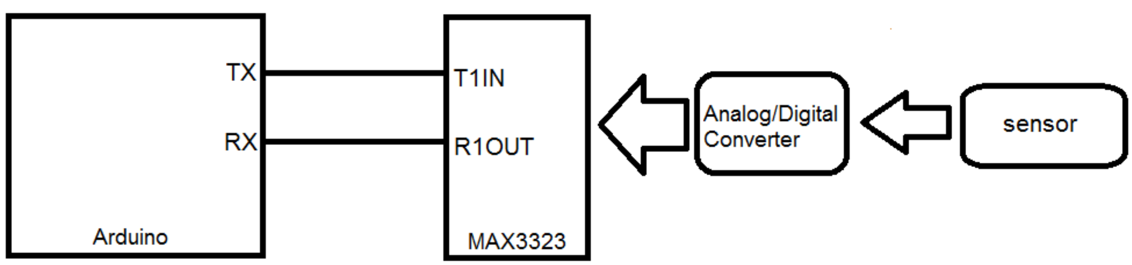

Figure 2.5: UART with MAX3323

Figure 2.6 shows a generic type of UART configuration in which each device can talk to the microcontroller at the same time, but they also each take up 2 wires during communication.

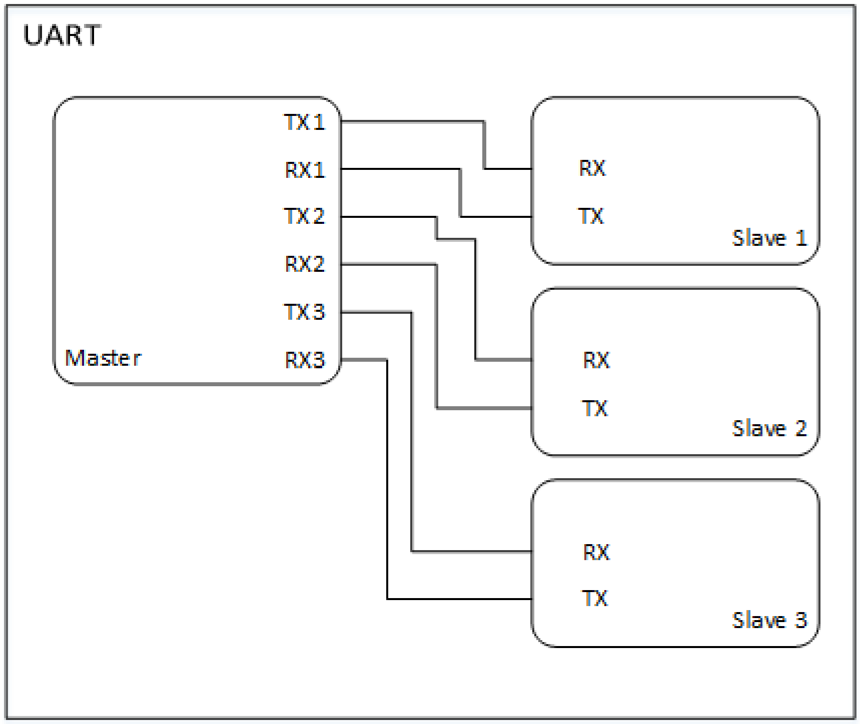

Figure 2.6: UART Diagram

I^2C - I^2C is short for Inter-Integrated Circuit. In order to incorporate the use of I^2C with the microcontroller, an I^2C communications interface between the microcontroller itself and the hydroponic sensors needs to be created. To achieve this, the microcontroller acts as a master, and the sensors act as slaves. The advantage to using this method is that there can be several sensors connected as slaves to the master. Each sensor is attributed an unique identification number, and sometimes the ID is pre-configured on some devices when they are purchased.

The I^2C method is a 2 wire communications link between integrated circuits. It was introduced by Phillips Semiconductors in 1980 for use in televisions, VCR's, and audio equipment. I^2C has 3 standard data transfer speeds, standard mode with 100Kbps, fast mode with 400 Kbps, and finally high speed mode with 3.4 Mbps. The I^2C bus supports 7 bits as well as 10 bits devices which may operate under different voltages.

Devices that already support I^2C can be directly connected to the bus. Analog devices can be connected to the I^2C bus by using analog to digital converters like the Philips PCF8591, or Analog Devices AD7992,or I/O expanders like either TI PCF8574 or PCF8575 with an I^2C interface.

The I^2C bus is comprised of 2 wires, and they are shared between the master and slave devices. These 2 lines consist of the data line, or SDA line, and the clock line or SCL line. These lines will allow the master and slaves to communicate with each other as shown below in Figure 2.7. As it is shown in this diagram, the SDA line is connected to a digital IO, and the SCL line is connected to another digital IO on the Arduino, which the I²C interface will take as it is initialized. Moreover, on the SDA line, connection happens in both directions.

I²C is an active low device, which means that the values need to be pulled low in order to be considered as logic "1". In order to do that, pull up resistors must be implemented. These resistors will pull up the volt to the default of 5V signal. The values used in these resistors could be $10k\Omega$ as shown in Figure 2.7.

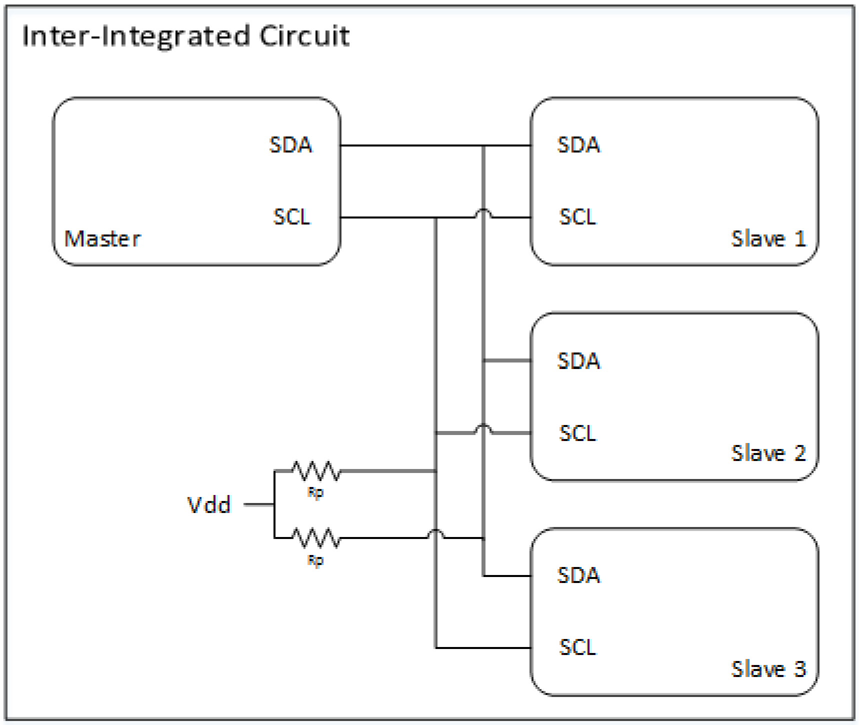

Figure 2.7: I²C Diagram

SPI - The Serial Peripheral Interface (SPI) is a synchronous serial data communication protocol which was developed by Motorola, and later adopted as a standard by many different companies in the industry.

The SPI bus operates in full duplex mode, which means that signals connecting data could go in both directions at the same time. Also, SPI is a synchronous data link setup type with master/slave interface pattern which supports up to 10Mbps of speed.

An SPI bus setup consists of 4 signal wires:

1. Master Out Slave In (MOSI): Represents a pin on the SPI capable IC in which the data signal goes from the master to the slave only.

2. Master In Slave Out (MISO): Represents a pin on the SPI capable IC in which the data signal goes from the slave to the master only.

3. Serial Clock (SCK): Represents a signal generated by the master which synchronizes the data transfer

4. Chip Select (CS): Represents a signal generated by the master to select individual slave devices.

SPI can operate in a single master device and with one or more slave devices. In order for the master device to start talking with a slave one, it should make its SS pin active low and then wait for at least a complete period of time before start issuing its clock cycles.

When it comes to incorporate the chosen microcontroller with SPI interface, the microcontroller is chosen to be the master and the SPI devices, or sensors, to be the slaves.

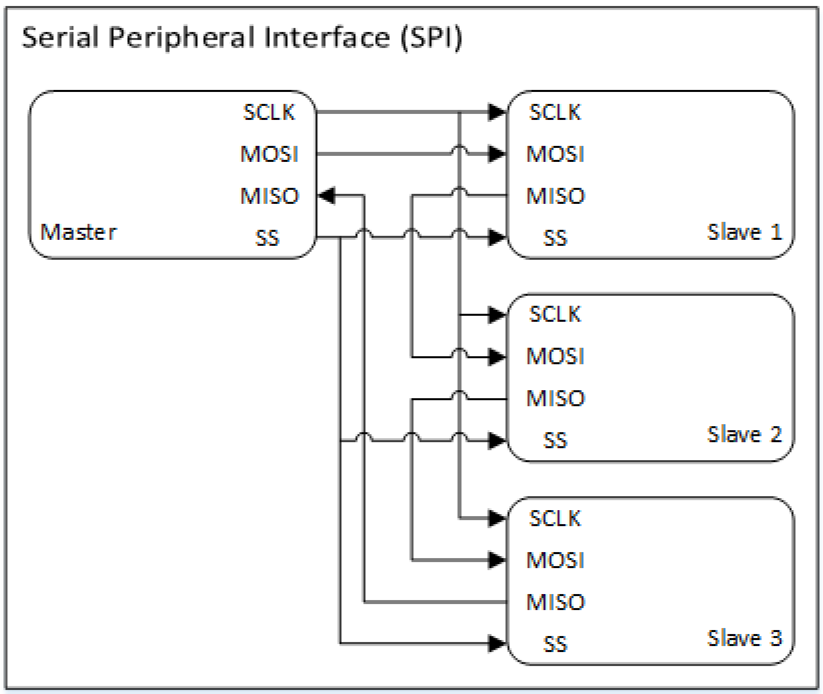

Figure 2.8: SPI Diagram

It is clear from Figure 2.8 that the SPI master device (microcontroller) is the one which takes care of sending logic "0" to the pin (Slave Select) of the slave device (sensor). It is also clear that it is responsible for generating clock signal to the slave to permit sending data on both master and slave data lines. In the case when more than one slave device needed to be available on the circuit board, then it is needed to have the microcontroller (master device) capable of having more than (Slave Select) pins one for each slave device. In order to choose one of these slaves for communications with the master, that particular pin on the microcontroller (master device) needs to be set to logic "0", and set the rest of them to logic "1".

2.5 Power Technology

There are three major goals for the design of this systems power supply. The power system must match the power consumption requirements of the design, it must generate and store energy efficiently, and it must not create any safety hazards during normal user operation.

The hydroponics system itself has only a few devices that consume power. The main control unit contains a microcontroller that will draw a small amount of power. The pump inside the hydroponics reservoir that will filter the water and provide oxygen will consume power continuously. There will be a few small pumps that will inject nutrients and pH solution into the hydroponics reservoir that will consume power intermittently.

In order to create a product that appeals to people with energy conscious minds, the hydroponic system is incorporating solar power generation as an optional method of powering the hydroponics system. Solar panels generate electricity when exposed to light, and the device will be outside during normal operation.

Because the system uses solar power, a battery is needed to provide a steady power supply for the microcontroller and other devices. This allows the system to run even when inclement weather is blocking light, or when the device needs to do something at night in the dark.

What also needs to be considered is matching the battery impedance with the solar panels so that the maximum amount of energy is generated for the battery. This means that the battery will need some type of charge controller that also regulates the input impedance from the solar panel. Schematics are freely available online for possible charging interfaces from solar panels to a battery.

2.5.1 Solar Generation

This hydroponic system is intended to sit outside during operation, being exposed to direct sunlight for healthy growth of the plant. The system will have a power connection for a solar panel which could be mounted on top of a roof, or directly to the hydroponics main control structure. The design requirements to be considered are the durability of the solar panel structure during mounting and weathering processes, and the overall voltage, current, and power characteristics of the available solar panels. In order to determine these characteristics, multiple types of solar panels are looked at.

Solar power is becoming a popular alternative to fossil fuels due to the rising price of oil. Solar cells are used to provide power to many electronics and buildings with electricity that is converted from sunlight. Solar cells consist of an array of p-n diodes that are designed with a variety different types of silicon and other semiconductor materials. Silicon is used a majority of the time for designing the solar cells because it is a very abundant resource that is readily available. Solar cell efficiencies are an important aspect in the design and are limited typically to around 15% for commercial solar cells.

The efficiency of a solar cell can be increased with a multi-junction solar cell, although this type of design is much more expensive than just plain silicon solar cells. Solar cells use semiconductor theory to create a voltage across a p-n diode. Solar cell technology works by producing a photocurrent in the semiconductor diode that is contained in the solar panel. When the emitter of the diode is introduced to direct sunlight then a photocurrent is established in the diode. Typically the diode of a solar has a substrate of p-type on the bottom or the solar cell and is doped on the top layer with n-type. The doping is unbalanced with the n-type section be doped heavier than the p-type substrate.

A few values that are of particular importance for solar cells are the open circuit voltage, the short circuit current, and the efficiency of the solar cell. The open circuit voltage (Voc) is the resulting voltage of the solar cell when there no current is being drawn from the solar cell. The equation for the open circuit voltage of a particular solar cell is described by the equation below.

$$Voc = Ut * \ln{(IL/I0 + 1)}$$

The short circuit current (Isc) is the resulting current in the solar cell circuit when it is short circuited and there is no voltage at the solar cell. This current value for Isc is equal to the current density that is generated by the light (IL). The efficiency for the solar cell is simply the ratio of the electric output of the cell to the luminous power that is being absorbed by the cell. The equation for the efficiency of a solar cell is shown below.

$$n = (Im * Vm)/P_{light}$$

Im and Vm are the voltage and current at the optimal operating point. All of the formulas give the characteristics of a given solar cell. Choosing the size of a solar cell is as simple as deciding how many watts you need to keep the battery charged to the correct voltage level and also power the system or device.

Polycrystalline Silicon Solar Cell - Polycrystalline silicon is a type of silicon that has been highly purified through a chemical vapor deposition process. Impurities that are present in the small grains of polycrystalline silicon seemingly creates a reduction in the overall efficiency of the solar cell. Although, efficiency reduction can be can be minimized with three processes that includes passivation using hydrogen ions, gettering using phosphorus, and gettering using aluminum. The polycrystalline silicon solar cell technology is a series of p-n junctions that are made from typically 10x10 cm^2 pieces of silicon that is doped first with a p or n material. Then, a p or n material is deposited into the bottom layer of the silicon along with metal contacts for both sections. The polycrystalline silicon solar cells have obtained efficiencies of approximately 16%. Figure 2.9 below shows an example of a polycrystalline silicon solar cell in which it can be seen the separation of grains in the impure silicon throughout the substrate.

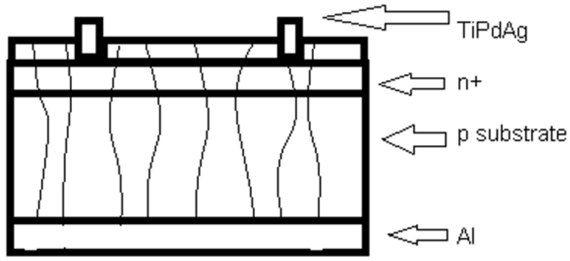

Figure 2.9: Seperation of Grains in Polycrystalline Subtrate

Monocrystalline Silicon Solar Cell - Another type of silicon material that can be used to produce solar cells is monocrystalline silicon which is also known as single crystal silicon. Monocrystalline silicon is created through the processing of polycrystalline silicon which involves growing it into a cylindrical structure of single crystal silicon by slowly pulling up molten silicon and allowing the molten silicon to harden into a solid. This process is called the Czochralski process, which is used to grow single crystal silicon. Solar cells made from this material is more expensive because of the process to create this silicon can only be conducted in a special facility. Monocrystalline silicon solar cells have a higher efficiency than polycrystalline silicon solar cells but they are more expensive which makes them less practical from an economical perspective.

Amorphous Silicon Solar Cell - A third type of silicon material used to produce solar cells is amorphous silicon. Amorphous silicon differs from silicon because its lattice does not have a strict periodicity, which is different from the lattice structure that exists in crystalline silicon. This has the effect of light being absorbed directly. A benefit of amorphous silicon for solar panel design is that it can be made with much less material than crystalline silicon. This material can be used for making thin film solar panels that have much less silicon than other solar cells that are known as wafer cells.

Thin Film Solar Cell - Thin film solar cells are an increasingly more popular solar cell because of their thin design which cuts down on the amount of silicon required for production. These solar cells have been integrated into everyday products for years such as simple calculators that are powered by solar cells. These devices are so common that they may go unnoticed by many people. Many thin film solar cells are being used to help provide power for buildings and parking garages. Universities are using them to cut down on their power bills. Thin film solar cells can be developed with amorphous silicon or with other materials such as cadmium telluride (CdTe), gallium arsenide (GaAs), and copper indium selenide (CISe) to create a solar cell having around the same efficiency as polycrystalline silicon solar cells. These solar cells have a thickness that is thinner than $50\,\mu m$ and are much thinner than the wafer cells discussed previously. The major benefit for thin film solar cells is they require much less silicon material to manufacture due to their small size. Thin film solar cells made from amorphous silicon are produced by deposition of singular layers in a high frequency glow discharge reactor.

2.5.2 Battery Storage

Batteries for electrical power storage are essential for anything that is going to be powered with solar power technology due to the absence of sunlight at night and during cloudy days. The solar panels must have the ability to store the energy into a battery during sunlight hours to be used when there is no sunlight. There are various types of batteries that can be considered for the electrical storage that is required for the solar panel power supply. Traction batteries are required for photo-voltaic applications because they are designed with a high ampere-hour capacity and are good for cycling.

Battery capacities are measured using Ampere-hour (Ah) which is the number of hours that the battery can last while consuming a specific amount of amperes. It is important to choose a battery with the right ampere-hour capacity to ensure that the battery holds enough charge to provide power during times when there is not as much sunlight available. For photovoltaic applications, certain specifications must be met to ensure a long lasting and efficient power system. The characteristics of different batteries vary greatly in respect to their effect on the environment, deep discharging abilities, total size, and their capacity. Photovoltaic applications of batteries require a large enough capacity so that the battery does not fully discharge during times when the solar panels are not producing power to the system. Choosing the right battery is critical for many reasons such as safety, cost, and reliability of the power supply system. This means that different types of batteries need to be compared in order to determine which type is best suited for the solar power or photo-voltaic energy system. Three types of batteries that will be considered are lead-acid batteries, nickel metal hydride batteries, and lithium-ion batteries.

Lithium-Ion Battery - Lithium-ion batteries are being used for many of today's products such as cell phones and more recently in electric cars and airplanes. Lithium-ion batteries are is a unique battery technology for the characteristic that there is a large variety of materials available for the electrodes that all come with different properties. These batteries could become even better with advances in research but they have been known to have problems with remaining stable in particular applications such as catastrophically exploding during their use in electric automobiles. In addition, lithium-ion batteries are not a very good choice for photo-voltaic applications because they do not have a very large capacity capability, which would be important for long periods of time with no sunlight.

Nickel Metal Hydride Battery - Nickel metal hydride batteries had originally been designed to replace nickel cadmium battery technology because of studies that prove how detrimental cadmium is to the environment. These batteries are able to get 1000-2000 cycles in their lifetime that makes them a good battery for applications that require cycling like portable electronics. Nickel metal hydride batteries are used for hybrid electric vehicles like its use in the Toyota Prius, but solar cell applications is not discussed that is possibly because they have a limited capacity that is not ideal for solar cell applications.

Lead-Acid Battery - Lead-acid batteries have been in use for a long time now and are commonly used in photo-voltaic applications. These batteries have a wide range of capacities that can go from 1 Ah for every individual 2V cell to several thousand Ah per cell. The lead battery's self discharge is low being between 2.5% and 5% per month and depends on the state of charge, composition of the electrodes, and also other factors. For photo-voltaic applications, vented batteries with tubular plates or sealed batteries should be used because in these specific applications de-stratification cannot occur due the fact that the battery might not reach the end of the charging phase which is when de-stratification happens. De-stratification is the process that eliminates stratified layers through mixture of the air or water. The longest lasting lead-acid battery in terms of charges and discharges for cycling applications is the tubular plates battery, which can last for 1800 cycles during a 50% depth of discharge. Other types such as Gel battery or AGM battery lasted for 650 cycles and 450 cycles according to *Lead and Nickel Electrochemical Batteries* [23].

2.5.3 Battery Charge Controller

A charge controller is extremely important for the power system. The current going from the solar cell to charge the battery must be regulated in order to keep the battery from overcharging. The charge controller can either be a stand-alone unit or integrated into the power circuit and in the case of a photovoltaic application it can be integrated into the circuit. Charge controllers are used in every photovoltaic application for the regulation of the power system. Although the power system is quite simple having only a battery and solar panels, the system must be regulated using a charge controller. Without the charge controller connected between the solar panel and the battery very bad things occur such as the battery getting overcharged or the battery being under charged. Both instances will greatly reduce the life of the battery. Also, the power system requires a Maximum Power Point Transfer (MPPT) that is used to obtain the maximum power transfer from the solar array to the batteries. This is important for the power system because otherwise there would be power loss across the system which would result in the battery not getting fully charged.

The key for creating a good charge controller is utilizing a circuit which matches the input impedance of the battery with the output impedance of the solar panel. This ensures that the maximum amount of power is being transferred to the battery.

The charge controller also needs a DC to DC converter that will change the voltage of the solar panel for the battery. Some examples of DC to DC converters are:

- Linear regulator
- Switched-mode conversion
- Switch-Capacitor converter

Linear Regulator - The linear regulator outputs a regulated DC voltage from the circuit that is dropped down in voltage from the input. This allows for a signal to go from a large voltage to a smaller that is required by whatever device that is being powered. The regulation is dependent on the size of resistors being used for the linear regulator circuit. The drop out voltage of the linear regulator is the minimum voltage required to maintain the output voltage regulation. Efficiency for the linear regulator is good for a low dropout voltage, but drops off considerably when the dropout voltage increases. A disadvantage of the linear regulator is that it only has the ability for step-down voltage regulation and not step-up voltage regulation. So, overall the voltage regulator is somewhat limited in its operation as a DC/DC converter because of its fall backs.

Switched-Mode Coversion - Switched-mode conversion circuit is made up of transistor switching devices and an inductor and have a power stage with a closed loop feedback controller. Three effective power stage implementations are the buck, boost, and non-inverting buck boost power converters. The feedback controller is what regulates the output voltage to a specific reference voltage. It also determines the duty cycle of the power stage duty cycle of the power stage which makes it able to obtain the specified output with high accuracy without regards to line, load, or component variations. Efficiencies for the switched-mode converters is over 90% for many different power levels and is relatively more sophisticated than the linear regulator.

Switched-Capacitor Converter - The switched-capacitor converter is similar to the switched-mode converter because it has the power stage and also the closed loop feedback controller. The power stage is an array of capacitors. Power switches and clock control signals are also used for the switching actions. The advantage of the switched-capacitor converter is that it uses capacitors that can be made very small compared to large inductors used in the switched-mode converter. Efficiencies for this converter depend on the design of the power stage and its switching actions.

2.5.4 AC to DC Converter

The hydroponics system is intended to only run on solar power but an alternative to using solar power is using power coming from an electrical socket in the form an AC signal. The electrical power that is sent to buildings and houses is in the form of AC signals because DC signals cannot travel long distances. They will disintegrate into nothing and all of the power will be lost across the line. Power companies providing power to people all across the country must send a signal that will travel along huge electrical grids without losing too much power. Some of the power that is sent from the power company will be lost anyway during transmission, but power loss can be greatly reduced in the circuit using AC instead of DC power. Edison proposed and suggested that AC power transmission should be used instead of DC, although the only way to accomplish DC power transmission into people's homes was by having individual electrical generators that produced power for individual houses instead of having one power plant to provide power to everyone. The latter is clearly the more practical and efficient way of providing electrical power, which means that this one is the method that is used by today's power companies.

The AC electrical signal coming to people's homes from the power company is standardized for everyone with consistent voltage and frequency components. The outlet's AC power coming off the grid is a 12V signal having a frequency of 60 Hz. For using this power in the hydroponics controller the AC signal must be changed to a DC signal that will be corrected to a specific voltage that is needed by the product.

This would change the entire design for the power system of the automated hydroponics system. Although, another option could be to design the device with the alternative power source in addition to the solar power, which could be used if solar power was not desired. The ac signal coming from a wall outlet will not work to power the parts of the hydroponics system such as the microcontroller and sensors. A dc to ac converter must be designed into the system to get the correct electrical signal to do this. The ac to dc converter is used to change the ac signal that is coming from wall sockets into a dc signal that can used to power electronic devices. This is a very simple circuit that consists of four diodes and a capacitor, also a transformer is used to change the magnitude of the input signal into the circuit. A circuit diagram for the full wave rectifier is shown below in Figure 2.10, which is complete with a transformer and load resistor for the output voltage.

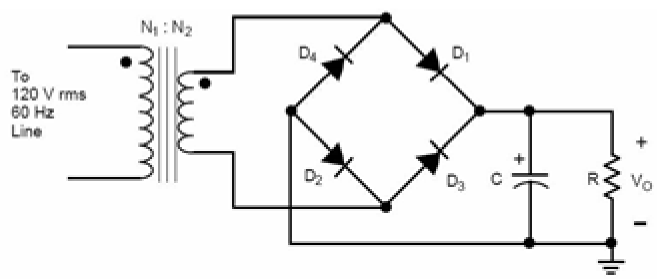

Figure 2.10: Full Wave Rectifier Circuit Diagram

The circuit above will effectively step down the voltage from the electrical outlet and transform the ac signal to a dc signal. The output voltage has now been rectified into positive signal and then turned into a dc value with the capacitor at the output. An op-amp can even be added to the circuit to get a more perfect resulting dc signal because it corrects for the diode's turn on voltage which changes the amplitude and duty cycle of the signal.

2.6 Physical Interaction

One of the main design objectives for this product is to create an advanced automation process that a user with no prior knowledge of hydroponics or electronics can control. The way that the user interacts with their machine with regards to issuing commands to the main control unit is a very important step towards fulfilling this objective.

Simplicity of the controls is the primary task that needs to be fulfilled. What is the minimum amount of control that can be provided while still supplying the full range of design features for the user? Are there some processes that the device should automate away from the user, such that they have no control over the process? These are the questions that need to be answered in order to properly design the physical aspect of the prototype module.

One necessary control is an ability to toggle the device on and off. A function like this can be achieved with a switch or button. The current state of the hydroponic system is then shown as a simple on/off LED light, showing the user if the device is running properly. If the light flashes on and off repeatedly, that could indicate that there is some sort of problem with the function of the device.

A possible interface could also be some kind of screen that displays information about the function of the device for the user. Perhaps there would be buttons to navigate menus for this screen, and options could be selected for the configuration of the device. How else could the user specify passwords for their wireless network? Maybe, the device just won't be able to connect to secured networks by design in order to simplify this process and remove the need for a display.

Other aspects of physical interaction include the setup of the hydroponic reservoir to the sensors and the main control unit. The device needs to be easily attachable and take up a minimum amount of space. Snapping plastic latches should be used for securing pieces of the device since these mechanisms are cheap and reliable for a system with low strength requirements such as this one.

2.7 Software

Software is a critical part of this project. It is needed to accurately program and run the microcontroller and is also needed to develop a web server design. Exploration was done on both of these software specific areas and the information shown below summarizes the analysis of the different areas.

2.7.1 Microprocessor Coding Environments

For this research, two different coding environments were explored. First, the Texas Instruments MSP430 coding environment was explored. TI uses Code Composer Studio (CCS) to program their microprocessors. The second environment explored is the Arduino IDE environment used with Atmel microprocessors. The analyses of both environments are shown below.

Code Composer Studio (CCS) - The Code Composer Studio environment used by TI is familiar to the members of this project and has been used in previous courses like embedded systems. With a good understanding of the environment, the MSP430 and CCS was the first exploration done. After research, it was found that CCS is only compatible with Windows and Linux operating systems. This could be problematic because some members of the group are using Macs. CCS also has no internal serial monitor program. It needs to be used in conjunction with programs like HyperTerminal or Putty. This project will be using a serial monitor very frequently to configure the Wi-Fi module's connection settings and preferences. CCS programs are written in C or Assembly languages and there are not many built external libraries to easily code and support communication with sensors and a Wi-Fi module. CCS requires users to purchase a license to use the product, but a free license can be obtained that limits the coding space to 16Kb.

Arduino IDE Environment - The Arduino IDE environment was the second environment explored and is the coding environment used with most Arduino based projects. An Arduino bootloader can be loaded onto Atmel microprocessors to enable them to run code written in the Arduino IDE. The Arduino IDE is cross platform and can run on Windows, Linux, and Mac machines. It includes a built in serial monitor program. Code is written in an Arduino language, which is based off of C but closely resembles C++ and the object-oriented model. The Arduino IDE offers plenty of external libraries for a multitude of functions. These include interfacing to sensors, communicating to Wi-Fi modules, and reading and translating inbound values from sensors and pins. Most importantly, the Arduino IDE and its libraries are open source with no limitations on coding space [2].

2.7.2 Web Servers

For this research, an exploration was done of different web servers, the setup process needed, and the technical knowledge needed to design and implement a web server that runs a custom website. First explored was Apache's HTTP server in conjunction with PHP. Second, an exploration was done on a new upcoming platform called Node.js. Both methods are summarized below.

Apache HTTP Server - Apache HTTP servers have been around since the mid '90s and are commonly used with PHP. They are open source and are cross platform, working on Windows, Linux, and Mac. Apache servers hold web apps, which are web pages being run on that server. Most web apps use PHP embedded in HTML to deliver dynamic content. Apache servers contain a configuration file that must be configured to run PHP. This configuration file must also be configured to run the server on a specific host and port. The configuration file itself is a long file that takes some time to understand what needs to be modified or added. The itemized list below shows the steps necessary to setup an Apache server running PHP:

- Download Apache HTTP server and PHP from their respective websites.
- Store the Apache server at the root level on a computer and open the configuration file.
- Modify the file to add the PHP module, host, and port desired.
- Start the server and run a PHP test to ensure proper setup.

PHP is the driving force behind Apache server websites and is used in a great majority of websites today. PHP is used in conjunction with a database language like SQL when connecting to a database. PHP is not a stand-alone program. It needs a server like Apache to be able to run. A disadvantage of PHP is that is has a blocking architecture. This means that that incoming PHP requests to the server from clients are handled one at a time. Multiple requests at the same time results in the server creating a new thread for each request. This blocking flow limits the number of requests the server can handle. PHP has also been known to have inconsistent API documentation. Some PHP functions are in camel case while others use the underscore notation. There are also some functions that are all lowercase and some functions that are duplicates of others. As a result, there is a larger learning curve when learning PHP.

Node.js - Node.js is a platform that allows users to create a web server and webpage in a single environment. All of the code necessary to create a web server on a specified host and port, and to create dynamic webpages can be written in JavaScript. The user only needs to download the Node.js software to start a project. Node.js is an up-and-coming platform that is being adopted by big companies like Walmart for many reasons. First, Node.js offers an integration of all services needed into one language. For example, connecting and using a database can all be done using JavaScript within Node.js. Users can import open source modules that extend the functionality of the platform. Modules have been written that connect to a database, send emails, send SMS text messages, login authentication, and many more. Node.js can create and run as server on its own without the need for any external programs. The main advantage of Node.js over other web servers is the non-blocking architecture. All events that happen in Node.js are asynchronous. This means that the server can handle multiple requests at the same time without creating a new thread for each request. This approach is beneficial to companies with large amounts of users because it increases performance and utilization. Node.js is also good for use in real time systems that require fast and reoccurring access.

2.7.3 Databases

When exploring the different databases out there, it is important to understand the functional concepts of the database and the differences between a relational and non-relational database. Each kind of database has applications that are suited for the specific structure and design to maximize efficiency and utilization. In deciding which kind is needed for this project, an analysis of each is needed.

Relational Database - A relation database allows information to be stored in tables that can relate to each other using underlying relational algebra concepts. First created in the 1970s to deal with the first wave of storage applications, database records are stored in rows and columns (like a spreadsheet) with each containing a specific piece of data for that record [28]. Queries on the database join tables together using relational algebra to produce the desired results. Database schemas are written in advance. Changes to these schemas can alter the entire database's relationships and the database may need to go offline [28]. Data manipulation is done through Data Manipulation Language (DML) and Data Control Language (DCL) in statements like "SELECT * FROM [table] WHERE [attribute] > 2." A common example of a relational database is a SQL database. SQL databases use syntax including statements like "SELECT, INSERT, UPDATE" to modify the data in the tables. Other examples of relational databases are Postgres and Oracle databases.

Non-Relational Database – Non-relational databases come in many different types, including key-value stores, document databases, wide-column stores, and graphical databases [28]. Each type stores data differently depending upon the type of application needed. Database keys, like a primary key, are used differently in each of the database types. Table 2.1 below summarizes the different types and their storage techniques [28].

Type	Description	Examples
Key-Value Stores	Each "key" (attribute name) is stored with a "value" representing the value in that attribute.	Riak, Voldemort, Redis
Document	Each "key" is paired with a complex data structure called a document. A document can contain multiple key-value pairs, key-value arrays, or nested documents. Documents are stored commonly in JSON and XML format.	MongoDB
Wide-Column Stores	Optimized for queries over large databases and store columns of data together rather than rows.	Cassandra, Hbase
Graph Stores	Used for storing information about networks like social connections or company hierarchies. Graphs store information like nodes, edges, and weights.	Neo4, HyperGraphDB

Table 2.1: Description of Different Non-Relational Database Types

These non-relational databases were developed in the 2000s to deal with the limitations of relational databases and provide a way for unstructured data storage [28]. Non-relational database schemas are dynamic and can be altered to add new attributes when needed. These changes can be added without the need for the database to go offline. Non-relational data manipulation can be achieved using object-oriented APIs. This is extremely useful for extracting information in object oriented PHP or Node.js environments.

2.8 Device Exploration

In this section, devices that are required for the proposed hydroponic system and which the design or implementation is not certain are explored. This identification of needs and recognition of upcoming challenges is necessary before the design and implementation of the actual hardware begins.

2.8.1 PH Sensor

One requirement of this automated hydroponics system is to measure and adjust the pH of the hydroponics reservoir. The pH is a logarithmic measure of the acidity of the water, and it is important that this value stays balanced for a given plant type that is growing in the hydroponics reservoir. The pH will constantly be affected by the plant, so the system needs be able to alter the pH of the reservoir using a chemical pH balancing solution. According to research done by numerous people running their own hydroponics systems, the optimum pH range for most hydroponics seems to be within the range of 5.8-6.2 [1, Ch. 2]. This allows the plant roots to absorb nutrients at the optimum rate. If the pH level leaves the allowable range that has been decided to be acceptable for optimum plant growth, then a buffering solution is added to affect the pH level, and bring it back within the acceptable range.

In order to know when the pH chemical needs to be added to the hydroponics reservoir, a sensor reads the pH every couple of minutes. Realistically, the pH level will not change dramatically and would only need to be monitored on a daily basis. Commercial pH sensing devices are too expensive for this system, so a custom sensor needs to be designed. The simplest version of a pH sensor consists of a glass electrode probe that is sensitive to the hydrogen ion concentration, which gives a voltage reading that corresponds linearly with pH. According to the *Environmental Instrumentation and Analysis Handbook*, glass pH electrodes are manufactured by creating a precisely formulated glass matrix gel layer of that is welded to an inert glass tube. The potential voltage measured by the glass directly measures the simplified pH definition, with a theoretical response of -59.16 mV/pH [27, Ch. 19]. An single junction glass electrode is shown in Figure 2.11.

The pH sensor is further improved by adding a gain stage with an operational amplifier that brings this voltage reading to appropriate values for the microcontroller to interpret. By using the voltage provided from the glass electrode probe, and combining it with a reference voltage from the operational amplifier gain stage, the pH analyzer will be able to relate the incoming voltage signal to a pH value.

Another improvement is to add a temperature sensor feedback stage that calibrates the pH reading with the current temperature, since the temperature affects the glass electrode instrument reading. Finally, a filtering stage can be added that removes noise signals that might exist in the pH reading, which should remain generally constant.

One thing to keep in mind with the pH sensor, is that various things can degrade the quality of the sensor readings over time. Dramatic temperature changes, for example, will asymmetrically affect the gel layer of the glass electrode, causing the slope of its pH response to increase or decrease [27, Ch. 19]. The other major problem that relates to this hydroponic system design is that undissolved solids in the water solution will coat the glass electrode over time, which slowly ruins the accuracy of the pH measure-

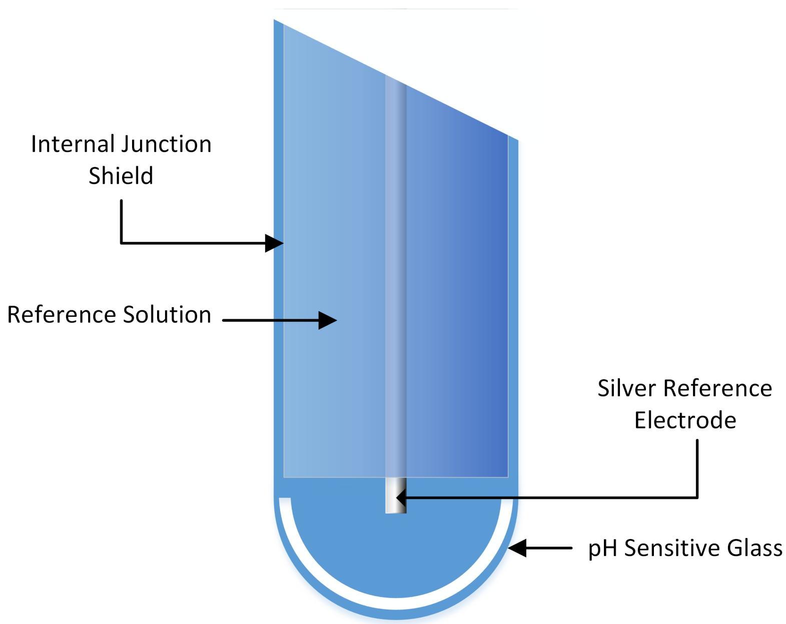

Figure 2.11: Glass Electrode PH Sensor

ments. The only way to deter this effect is to either maintain a flow rate of the measured solution over the sensor, or to enact a method of cleaning the sensor while it stays in the solution. Both of these solutions are impractical for this hydroponic design, so the degrading pH measurement must be an acceptable downfall to this prototype's design. The glass electrode can be cleaned and re-calibrated if the measurements become unacceptably inaccurate.

If the sensor is mounted properly, major problems can be easily avoided with the measurement of pH in the hydroponic solution. One important consideration is that the pH probe can have retraction capability in order to minimize the glass electrode's contact with the process.

Environmental Instrumentation and Analysis provides a good set of considerations for mounting the pH sensor:

1. The sensor shall be mounted so that it remains in continuous contact with the measured solution.

2. The sensor and microcontroller analyzer shall be easily accessible in case the probe requires maintenance.

3. Nutrients and pH buffer will disrupt the pH sensor if the solution has not been properly mixed before reaching the sensor.

4. The glass electrode shall not be exposed to high temperature or liquid pressure.

5. The glass electrode shall be placed as far from locations that sediment might settle on surfaces as possible, usually in the center of the measured solution.

2.8.2 Electrical Conductivity Sensor

A major requirement of hydroponics systems is the constant measurement and adjustment of the nutrients level that exists in the water which the plant absorbs nutrients from. Typically, this is done with a meter that can measure the total dissolved solids (TDS) content in a solution. The nutrients solution consists of nitrogen (N), phosphorus (P), potassium (K), and many other smaller concentrations of elements such as calcium, magnesium, sulfur, iron, copper, manganese, boron, zinc, molybdenium, and cobalt [1, Ch. 2]. The nutrient levels are designed to be balanced so that you can add in a variety of these elements and the plant will respond favorably.

Different types of plants respond to different concentrations of nutrients, and, in order to maximize the plants health and growth rate, varying nutrient solutions can be added for different plants. Multiple nutrient solutions can also be used with a singe plant by changing which solution is used depending on the stage of growth that the plant is in. For instance, the phosphorus level enhances the growth rate of immature plants, while high potassium levels contribute to the growth of the fruits that are harvested during the flowering stage of plant growth.

Because this system is designed to be more simple for the user, a single commercial nutrient solution is going to be used across all stages of the plant's growth. This is a commercial solution that can be ordered from any hydroponics or gardening store, and will be added to a refillable container on the actual prototype unit.

Like the pH sensor, there is a problem of finding an accurate measurement device that is affordable, reliable over many uses, and that remains accurate even after months of being exposed to the actual water solution. The main method for sensing the TDS of a solution is by measuring the electrical conductivity of the solution and then converting that value into an estimate of TDS using the known nutrients that exist in the water.

Environmental instrumentation and analysis handbook [27, Ch. 23] provides a set of criteria for the selection measurement technique when measuring the conductivity of the water. Figure 2.12 was created using data gathered from this handbook [27, Ch. 23.4].

1. If the solution being measured is corrosive or has a large amount of undissolved solids in it, then a toroidal sensor is required due to the fact that it measures the solution without making physical contact.

2. Extremely sensitive electrical conductivity requirements are better suited towards 4 contact electrode measurement, as it is much more sensitive to electrical conductivity below values of 10 uS/cm.

3. If maintenance is undesirable, toroidal sensors are preferred, though they do tend be more expensive.

4. Contact electrode probes are easier and cheaper to use than toroidal sensors, but they are more easily damaged and susceptible to errors in measurement.

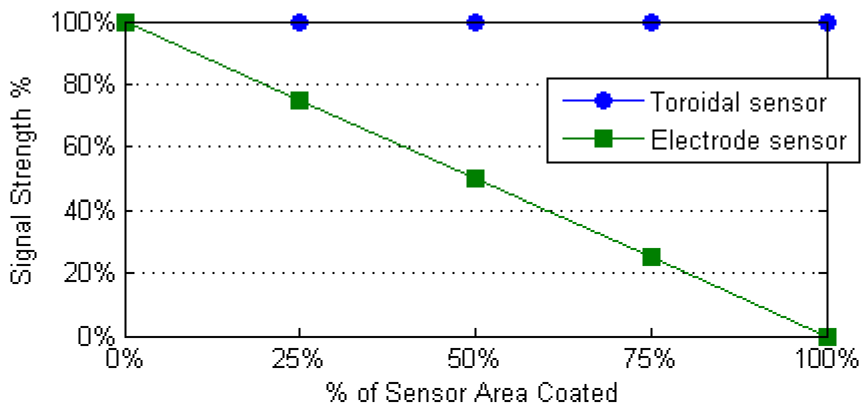

Figure 2.12: Deterioration of Electrode vs Toroidal Sensors

Toroidal methods are generally favorable because they do not actually make contact with the solution, allowing them to remain in the process without maintenance. Toroidal sensors are not as sensitive as the more common four electrode sensor detailed in *A Four-Terminal Water-Quality-Monitoring Conductivity Sensor.*[29]. There are trade-offs to using either sensor, but commercial implementations of both can be bought and used for testing in the initial prototype of this hydroponic system.

2.8.3 Temperature Sensor

Temperature of the reservoir water is an important parameter to measure with hydroponics applications because it is necessary to know the temperature to obtain accurate EC meter readings. It is also important to make sure that the overall system temperature is not getting excessively hot or cold so that the electronic sensors work correctly and the plant grows healthily. According to the circular publication, *Hydroponics as a Hobby* [30], warm season vegetables and flowers grow best between $60\,^{\circ}$F and $80\,^{\circ}$F. Freezing temperatures are especially dangerous to the hydroponic system because the pH sensor can break if the liquid inside it freezes.

There are two main types of temperature sensors that are commonly used with electronic devices: Contact sensors that bring the sensor into direct contact with the substance that it is measuring, and non-contact sensors such as infrared devices that measure temperature by sensing the infrared radiation emitted from a substance. Contact sensors are more appropriate for this hydroponic application due to their simplicity of installation and low cost.

Within the realm of contact type temperature sensors, there are two main methods of getting a temperature reading. The sensor will either use varying voltage signals, like in thermocouple devices, or resistance values derived from input voltage and current, like in thermistors and resistance wires [31].

Thermistor - The thermally sensitive transistor (thermistor) works by having a predictable resistance for given temperatures. Because the resistance of the transistor decreases as its temperature increases at a known rate, then the resistance measured over the transistor can be extrapolated into a temperature measurement. Resistance wire detectors work in a similar way, because the resistance across the junction increases as the temperature increases at a known rate.

Advantages:

- Resistance Wires can measure large areas rather than single points, so the measurement can be considered more reliable
- Low cost: Thermistors used over limited temperature ranges can be much less expensive than other methods due to common materials and circuit simplicity

Thermocouple - Thermocouple sensors work by creating a junction with two different materials that respond to temperature changes differently, therefore creating a voltage potential different. This voltage signal is usually in the range of a few millivolts.

Advantages:

- Response time: The thermocouple has an almost instant response to temperature changes
- Durability: The simplicity of the parts allows the device to withstand shocks easily
- High Temperature Reading Capability: Some thermocouples can read temperatures as high as $3100\,^{\circ}$F [31].

2.8.4 Light Sensor

One of the objectives for the hydroponics device is to be able to sense when it is day and night for diagnostic reasons. In order to accomplish this task, a certain type of light sensor needs to be implemented into the device. There are many different types of photosensors that could be considered. A list of these different types of photosensors is discussed below.

Photoresistor - A photoresistor is a resistor which has variable resistance based on the light intensity upon the device. The resistance of the device will decrease as more intense light is shined onto the sensor, which is easily implemented into a light sensor by measuring either the voltage across the resistor or the current flowing into the circuit.

This type of photosensor is commonly used in applications for sensing the switch between night and day, such as in:

- Alarm clocks
- Street lights
- Camera light meters

Photodiode - A photodiode is a semiconductor device, which takes advantage of the electromagnetic radiation of light and the photoelectric effect in a p-n junction. When photons hit the diode, an electron hole pair is created which creates a photocurrent. There are two modes that this device can be used. In photovoltaic mode, current flow out of the device is restricted thus building up voltage. In photoconductive mode, the diode is reverse biased. This causes the photo current to become linearly proportional to the illumination of light upon the diode.

Phototransistor - One type of photodiode is the phototransistor. The two corresponding types of phototransistors are, of course, the bipolar junction phototransistor and the field-effect phototransistor. These transistors have their respective base collector junction or gate source junction exposed to light, making the device susceptible to the photoelectrical effects of the photodiode. In this way, a phototransistor acts just like a photodiode with an amplification of the signal.

Phototransistors and photodiodes are commonly used in:

- Camera sensing equipment
- Street light sensors
- Optical LED switches

2.8.5 Water Supply Valve and Sensor

One of the minor parameters that the hydroponics system can measure and notify the user in case of a problem is the water level. In order to work properly, the deep water culture hydroponics system must have a water supply that reaches the very top of the water reservoir. In order to make sure that the water supply stays at the highest level, a valve of some sort can be used with a hose connection or even a secondary water reservoir.

The simplest type of water valve would bypass all of the electronics of the hydroponics system entirely, and, instead, a mechanical system can be used to ensure that water will enter the reservoir to keep it full.

The most common use of this technology is in most American people's bathrooms, keeping their toilets water supply full yet not overflowing. This is accomplished with the use of a float valve. The float valve works by taking advantage of the buoyant force of water to close the valve that is filling the reservoir. In this way, a balance is achieved where the water fills itself up and seals out any excess water.

One thing to be careful of with the water level in the hydroponics system, however, is that rain water or water that gets into the reservoir through outside means must be dealt with to prevent overflow. An easy way to solve this problem is to create safety drain holes at the highest levels of the reservoir, which will allow any excess water to escape out of the reservoir without getting into the electronics devices or ruining the plants.

Another improvement can be made with regards to the automation of this hydroponics system and its water level is by adding a water level sensor to the system. In the case that the user might have accidentally unplugged the water supply hose and forgotten to plug it back in, the plant will drink water and water will evaporate from the reservoir until the supply is completely depleted. A water level sensor will detect when the water level becomes too low, and can alert the user that the water supply has become disconnected.

Water level sensors are very simple to interface with a microcontroller, and they are also very inexpensive. The water level sensor can be a simple switch device that operates on the same principal as the float valve, taking advantage of the buoyant force of water to close or open an electrical switch.

2.8.6 Water Filter and Oxidation

As the plant goes through the growth process, it needs a few basic ingredients. Light and oxygen drive the photosynthesis process by which the plant gains energy, which comes from the sun and free carbon dioxide in the air which the plant breaths. It also uses oxygen in the water that it drinks, and because this hydroponic system might not be cycling the water at a high rate due to conservation reasons, the oxygen content in the water needs to be replenished.

Some hydroponics techniques take advantage of the filtration method to keep the nutrient rich water supplied with an adequate amount of oxygen. Water that is constantly being aerated over the roots or dripped into a nutrient reservoir and drained will maintain high levels of oxygenation for the plant, and do not need a stage of additional oxygenation.

The hydroponic system that is being proposed now does not have this feature, and will need a supplemental supply of oxygen. It could use what is referred to as an air stone. Similar to what could be used in a fish tank for fish to breathe, a filtering device will actually add dissolved oxygen to the water, aiding in the plants growth. Another function that the filtering device serves is to remove any undissolved solid contaminants in the water. The water should be completely clear and not be dirty at all in an ideal hydroponics system setup, so the filter helps to contribute towards this goal.

One way of finding out the actual dissolved oxygen content in a water sample is the measure the Oxidized Reduction Potential (ORP). This can give you an idea of how 'alive' or 'dead' the water is, since it measures the amount of electrons currently in the water. Some hydroponics devices use this sensing device to measure the amount of bacteria that might be helpful towards the growth of their plant, while other hydroponics systems focus on keeping a sterile environment for the plant to grow in without any bacteria. Another use for this type of sensor is to measure the amount of ozone in the water, which is a way to control the pH level of the water without adding pH buffer solution.

For many simple hydroponics systems, however, the ORP sensor does not give enough meaningful data to act on, thus it would be a waste to incorporate it into the design needlessly.

2.8.7 Liquid Nutrients Dispenser

Due to the nature of this hydroponics system, nutrients and pH buffer solution will need to be added to the hydroponic reservoir in order to provide optimum growth for the plant. In order to inject liquid solutions in a reliable manner that can be controlled electronically, some variation of a positive displacement pump should be used.

Pumps that have the capability to move liquids have been designed in many different ways, and come of these variations are easily ran with a simple DC motor that pushes the liquid through tubing. The most common type of DC motor liquid pump is called a centrifugal pump, because the design is the most straight forward to implement. The disadvantage to this type of pump is that the flow of liquid is not precisely controlled through the tubing. It cannot be stopped and started accurately either, as the liquid is free flowing through the pump tubing.

The type of pump required for this design is a positive displacement pump. These pump designs are characterized by the fact that the liquid that goes through the system is the same for every pump cycle, such that the amount of liquid displaced can be accurately controlled by varying the motor speed or controlling how many times the motor spins.

One type of positive displacement pump that would work well for this design is the peristaltic pump, which functions in a similar way to the digestive system of humans. This type of pump uses flexible tubing and a single spinning dc motor to control the flow of liquid, and is suitable for use in fish tanks and hydroponic environments.

Precaution needs to be taken because these pump implementations use a DC motor, which needs to remain in a dry, non-humid environment to function properly. Also, care needs to be taken not to block the tubing of a positive displacement pump, as the motor will continue to try jamming more and more liquid through until something breaks.

2.8.8 Wi-Fi Transceiver and Antenna

One of the device specifications is that the device will connect to the user's wireless network and transmit information about the plants growth to a hosted web server that can be accessed by the user through an application or website. In order to facilitate this connection with the user's wireless router, a Wi-Fi transmitter needs to be implemented onto the main control unit.

These type of transmitters come in low cost and low power variations that are ready to be interfaced with microcontrollers. The devices are configured using programmable memory for different connection settings and can be commanded to wake up periodically, send data, and then go back to sleep automatically. There are so many types of transceivers modules available in the market which can be chosen. All of these are categorized by criteria like supply voltage; frequency range; data rate; sensitivity; packaging types; and output power. The most common sizes for output powers are either 10 dBm, 12 dBm and 15 dBm.

Texas Instruments' SimpleLink^{TM}CC3000 - The TI CC3000 Wi-Fi module is a wireless network integrated circuit with IEEE 802.11 b/g and embedded IPv4 TCP/IP stack. It can transmit up to +18.0 dBm at 11 Mbps, CCK and has a receiver sensitivity of –88 dBm, with 8% Packet Error Rate (PER) at 11 Mbps. TI CC3000 requires less instructions per second so it can be used with simple microprocessors, and it has small memory footprint. Table 2.2 briefly represents some of this transceiver radio's characteristics.

Parameter	**Specification**
Frequency	2.4 GHz
Modulation	CCK and OFDM
Data Rate using 802.11g	6-54 Mbps
Receiver Sensitivity	-97 to -75 dBm typical
Maximum Output Power RMS	14.0 - 18.3 typical dBm

Table 2.2: Specifications from TI CC3000 Datasheet

Other TI CC3000 WLAN Features [22]:

- Auto-calibrated radio with a single-ended 50Ω interface enables easy connection to the antenna without requiring expertise in radio circuit design.
- Supports all Wi-Fi security modes for personal networks: WEP, WPA, and WPA2 with on-chip security accelerators
- Integrated IPv4 TCP/IP stack with BSD socket APIs enables simple internet connectivity with any microcontroller, microprocessor, or ASIC.
- Supports four simultaneous TCP or UDP sockets.

- Built-in network protocols: ARP, ICMP, DHCP client, and DNS client.
- Interfaces over 4-wire serial peripheral interface (SPI) with any microcontroller, or processor at clock speed up to 16 MHz.
- Integrated EEPROM stores firmware patch, network configuration, and MAC address.
- Programmable through an I2C interface or over APIs from the host, allowing over-the-air firmware upgrades.

It is also important to know the power consumption of the Wi-Fi Transceiver which is being implemented since it will affect the overall power consumption of the hydroponic system. What is necessary to look at is the amount of current the transceiver consumes when it is either sending data through TX port, or either receiving data through RX port. Table 2.3 below shows the power consumption data for given test conditions.

Parameter	**Test Conditions**	**Typical**	**Maximum**	**Units**
802.11b TX Current	Vbat = 3.6V Tamb = 25 °C Po = 18 dBm, 11 Mbps L = 2048 bytes tdelay (idle) = 40µs	260	275	mA
802.11g TX Current	Vbat = 3.6V Tamb = 25 °C Po = 14 dBm, 54 Mbps L = 2048 bytes tdelay (idle) = 40µs	190	207	mA
802.11bg RX Current	Vbat = 3.6V	92	103	mA
Shutdown Mode	Vbat = 3.6V	-	5	µA

Table 2.3: CC3000 Power Consumption Chart

The advantages of using this Texas Instruments Wi-Fi module is that the part has a very minimal impact on the financial budget for this project. Free samples can even be obtained and used for testing the interface with the microprocessor before it is surface mounted on the PCB. A disadvantage to using this product is that the antenna would have to be designed with considerations on its placement and signal strength when near other active devices.

Roving Networks' RN-131G Transceiver - The RN-131G module is a stand alone, embedded 2.4GHz IEEE 802.11b/g transceiver. Its throughput could go up to 1Mbps sustained data rate with TCP/IP and WPA2. It also has an on board ceramic chip antenna and U.FL connector for external antenna; 8 Mbit flash memory and 128 KB RAM; UART hardware interface; 10 general purpose digital I/O; Real-time clock for wakeup and time stamping and it supports Adhoc connections.

In order to determine whether or not the RN-131G transceiver will conduct a decent and stable 802.11b/g communication with the customer router, then the radio characteristics (frequencies, modulation, channel, transmission) associated with it need to be analyzed to have a comprehensive vision about its wireless capabilities and power. Table 2.4 briefly represents some of the RN131G transceiver radio's characteristics.

Parameter	**Specification**
Frequency	2412 to 2462 MHz
802.11b Modulation	DSSS
802.11g Modulation	OFDM
Channel Intervals	5 MHz
Channels Supported	1-14
Data Rate using 802.11b	1-11 Mbps
Data Rate using 802.11g	6-54 Mbps
Receiver Sensitivity	-85 dBm typical
Power Output	0 - 12 dBm

Table 2.4: Specifications from RN-131G Datasheet

On the same board where the RN-131G module is mounted on, there should be an antenna device which works hand in hand with the RN-131G module. One commonly used antenna is the Rufa 2.4 GHz SMD which is intended for Wi-Fi, Bluetooth or Zigbee applications. An important precaution to keep in consideration is that this antenna uses a ground plane in order to radiate efficiently, but this ground plane must not extend underneath the antenna itself. The antenna comes in two versions, with the feed locations on the right hand or left hand side of the antenna. The RUFA antenna's weight is very small, however its efficiency is very high. Table 2.5 lists a series of specifications that the RUFA Antenna Achieves.

Item	**Description**
Antenna Type	Quarter Wave
Frequency	2.4-2.5GHz
Connector	SMD
External	N
Impedance	50Ω
Peak Gain	4.4 dB
Polarization	Linear
Operating Temperature	$-40\,°C$ to $85\,°C$
Dimensions	12.8 x 3.9 x 1.1 mm
Weight	0.1g

Table 2.5: Specifications of the RUFA SMD Antenna

The advantage to using the Roving Networks Wi-Fi module is that it has extensive documentation and example projects that have already been set up with the Atmel microprocessor that has been selected for this project. Another benefit to using this device is that the Wi-Fi module and a working antenna are already surface mounted on their own PCB, and this PCB can be either surface mounted onto another PCB or mounted nearby and out of the way.

A disadvantage with this Roving Networks Wi-Fi module is that it is more expensive than the previous options, and the module and antenna cannot be ordered as free samples but must be purchased at full price. This would be a good module for a hobbyist to use in their own project, but not a good module for use in many manufactured products.

2.8.9 Camera

Cameras are integrated into almost every modern electronic device that is used such as cell phones, computers, and gaming systems. They are used to take videos and pictures or to enhance the gaming experience like with the most recent Xbox One and Sony Playstation 4 releases. They are referred to as image sensors by the industry and can be used to do many things. An image sensor can be implemented by the hydroponics project to send images to the user. This attribute is relevant because it goes along with the project's theme of having a hydroponics system that does not have to be manually maintained and looked after by the user. It allows the user to visually see any problems happening to the plants being grown without having to constantly check on them. The two image sensor technologies being used today are Charge-Coupled Devices (CCD) and CMOS image sensors. They are very different in how they obtain images which means advantages and disadvantages for the application of either one.

Charge-Coupled Devices or CCD image sensors are built with an array of capacitors that convert light intensity into voltages that can be transferred into digital signals. It is designed with MOS capacitors on a silicon substrate. This type of image sensor of very expensive and generally used for high performance products and not used in consumer digital cameras. It is used for applications that require the added quality such as by astronomers, scientists who need them for their research laboratories, and professional photographers. Therefore, it is far too expensive for the hydroponics project that uses the application of a camera that sends images back to the user for observation.

CMOS image sensors are known as active-pixel sensors because they are made of an array of photodetector sensors that detect the light at each pixel of the image. These sensors are much more affordable than the charge-coupled device sensors which leads to them being used more in consumer products such as in cell phones. The main disadvantage that this type of sensor has is rolling shutter when capturing video because of the speed. Although, this does not matter for this hydroponics project because only still images will be taken and not video.

Omnivision OV7960 - The Omnivision OV7690 image sensor is a VGA CMOS sensor that has full functionality of a single-chip VGA camera using OmniPixel3-HS technology in a small package. The sensor has an active image array of 1300 by 1028 pixels having a separate sensing element for every pixel. It has many features contained within it such as full-frame, sub-sampled, and windowed or scaled 8 bit/10 bit images that is adjusted from the Serial Camera Control Bus (SCCB) interface. These features are nice additions to a fairly competent image sensor, but they do not replace the performance of a CCD image sensor. The required image processing functions such as exposure control, gamma, white balance, color saturation, hue control, defective pixel canceling, noise canceling can be programmed through the SCCB interface. The maximum pixel rate is 60 frames/second which corresponds to the pixel clock rate of 48 MHz. The OV7960 image sensor pin diagram is shown in the figure below. Figure 2.13 below shows the functional block diagram of the OV7960 image sensor.

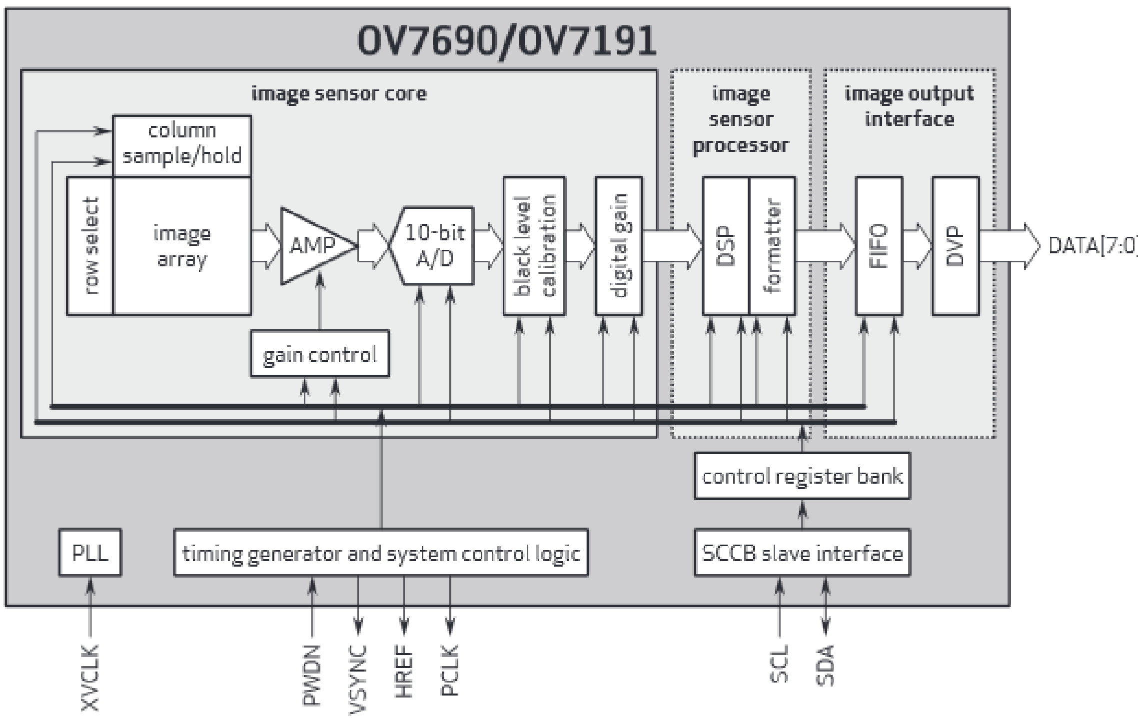

Figure 2.13: Functional Block Diagram for OV7960 [14]. *Consent to reproduce figure requested*

Texas Instruments TC341-20 - The Texas Instruments TC341-20 is a high performance frame-transfer CCD image sensor that is designed for black and white video and computer camera applications. This sensor has four basic functional block that include the image-sensing area, the image storage area, the serial register, and the charge detection amplifier. These separate blocks work by doing individual jobs in conjunction to effectively capture an image with the sensor. The serial register, for example, will transport the charge stored in the individual pixels of the memory to an amplifier. Next, the charge goes to the detection node where a transistor effectively senses the change in charge. Figure 2.14 below shows is a representation of the sensor with the separate parts labeled in the diagram.

The image sensor descriptions of the TI TC341-20 and the Omnivision OV9655 demon-

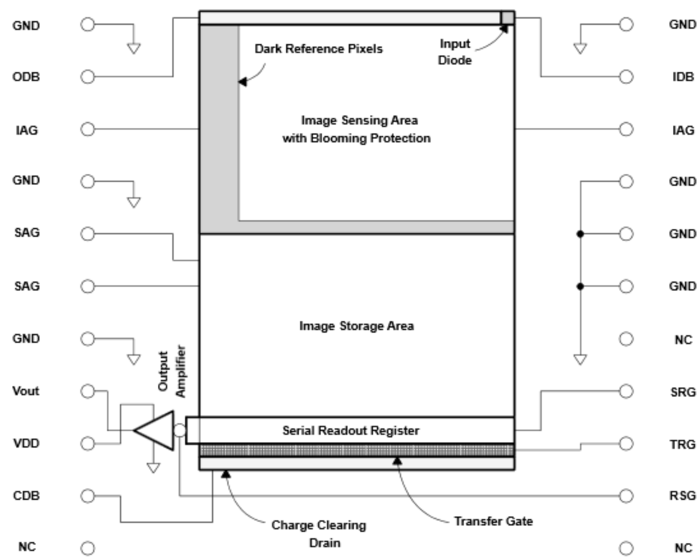

Figure 2.14: Texas Instruments TC341 Image Sensor Diagram [21]. *Consent to reproduce figure requested*

strates the large differences in the CCD and CMOS image sensors, which can also be seen in the price as well. The next step for the camera unit is interfacing it with the microcontroller effectively so that there is full functionality of the device. This will require some type of digital communication port from the microcontroller such as SPI, I2C, or two-wire serial communication to communicate with the camera. The image sensor must also be connected to the microcontroller to send the image in the form of digital signals to back to the microcontroller for processing. To accomplish this the sensor is connected to multiple digital input pins on the microcontroller in which it can input the data into the microcontroller. The data is transferred into the memory of the device via registers where it can be stored and eventually be sent out through a wired or wireless connection to another device. This equates to certain requirements for the microcontroller being necessary for this implementation such as the memory size and the number of pins available on the microcontroller. Additional memory can be added to meet the requirements but the number of pins available is a set for the particular microcontroller.

Chapter 3

Hardware and Software Design Details

Now that all of the major components and useful measurement techniques for the hydroponics system have been researched and weighed against each other, the design proceeds and specific choices are made with regard to which techniques should be implemented. Ultimately, the design decisions made for specific hardware subsystems are based primarily on simplicity and ease of installation into the main system. The secondary consideration for specific hardware subsystems is maintaining a design with as low of cost parts as possible while also staying within the design's specifications.

The design of the system will proceed as follows:

1. A flow chart block diagram is developed as an easy reference for viewing which devices communicate with each other device.

2. Specific subsystems are designed in detail to bring clarity to how the individual devices will be created in the prototype.

3. Finally, an overall design summary brings a full schematic view of all parts close together for review.

3.1 Hardware Block Diagram

The block diagram shown below in Figure 3.1 is a basic layout of the hardware design that will be used for the automated hydroponic system. The power supply consists of a battery and a solar panel that will charge the battery when exposed to sunlight. The power supply gives power to a device enclosure that houses the printed circuit board, electrical motors, and other electrical circuitry. The microcontroller receives data from the hydroponic system via a multitude of sensors that connect the device to the reservoir where the plan grows. Using this data, the microcontroller controls the pH level and the nutrients level in the reservoir water by adding solutions that either change the pH or contain dissolved nutrients to feed the plant. This requires two small pumps; one pump for each liquid. In addition, the microcontroller communicates with a Wi-Fi transceiver to send data to a hosted web server.

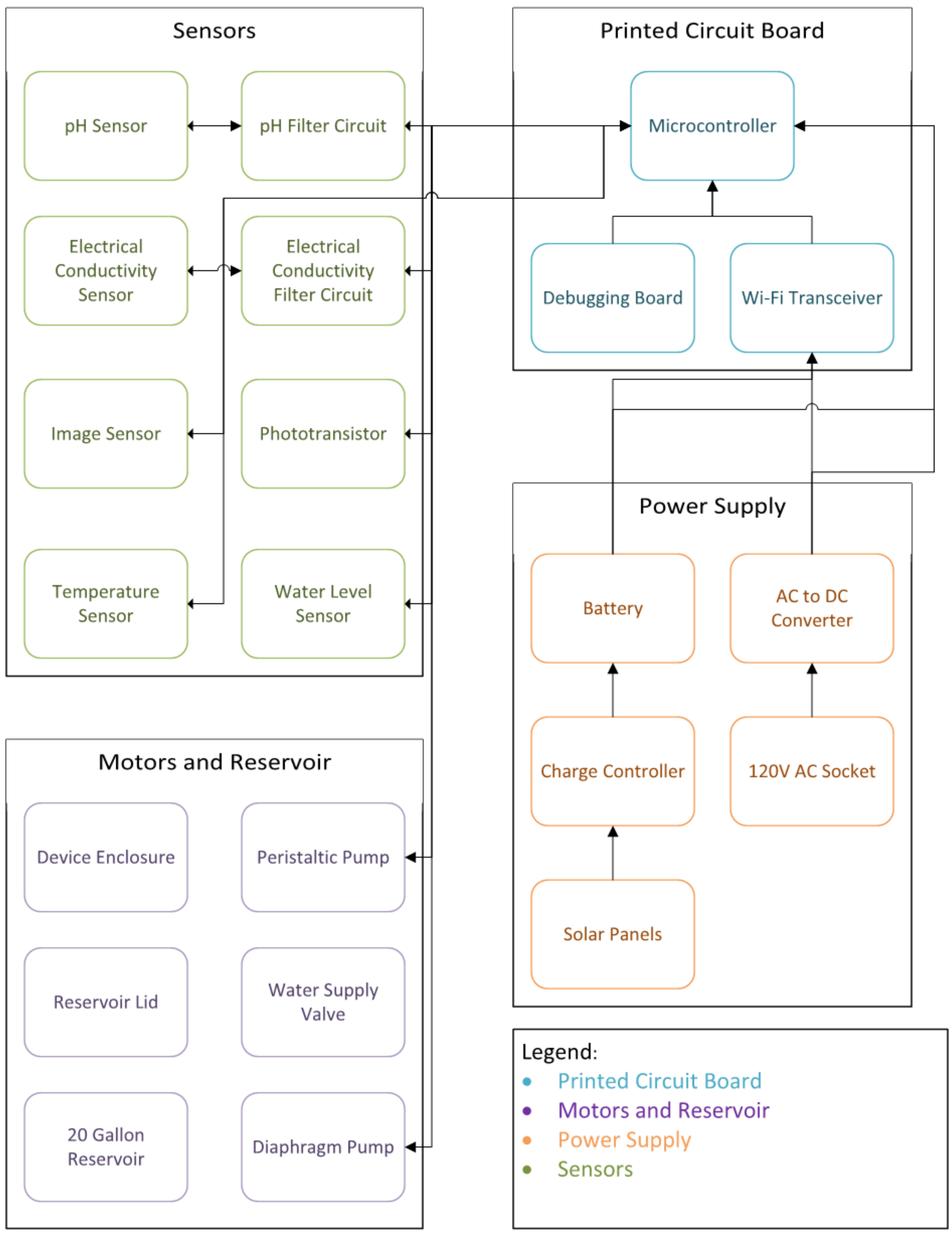

Figure 3.1: Hardware Block Diagram

3.2 Software Block Diagram

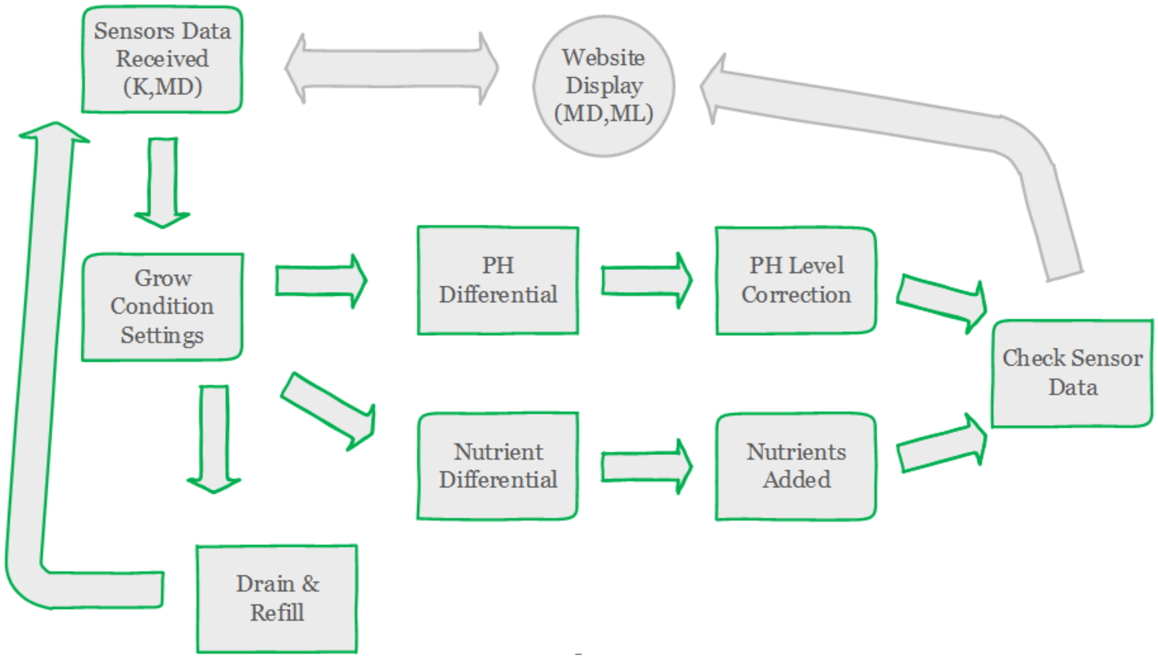

Figure 3.2: Software Block Diagram

The block diagram shown in Figure 3.2 above is a basic representation of how the software used for the automated hydroponics system will work. It starts off by taking the data from the sensors located in the system and displaying the data on the website. Then, with the settings for the grow system that are programmed into the microcontroller, it can find the difference between the desired value and the actual value for the PH and nutrient levels. With this calculation the software should know the approximate amount of Acid/Base or nutrients that is needed to be added to the system. The last step should be to display the updated PH and nutrient levels on the website along with the temperature of the water. Then program starts over and should be in a continuous cycle so it can maintain the PH and nutrient levels in the hydroponics system.

3.3 Hardware Subsystems

Each subsystem in this section consists of parts that are to be ordered so that they match the given specifications, and are readily available to be purchased or designed from scratch. First, the objective that the device fulfills is stated, and then the function and design of the part or parts is shown.

3.3.1 Electrical Conductivity Sensor

The electrical conductivity sensor allows the hydroponics device to create routine sensor readings for the total dissolved solids content in the water. This is the primary metric that the device uses to determine when nutrient solution needs to be pumped into the reservoir where the plant roots are. The reading will first be measured as a current flowing across a sophisticated probe gap, and the total dissolved measurement will be interpreted from the conductivity value based on knowledge of which nutrient solids are being pumped into the device, and how these influence the conductivity of the water.

The main objectives that this subsystem need to accomplish are:

- Measure the Siemens per meter conductivity parameter of the reservoir water supply.
- Send electrical conductivity sensor voltage readings through a circuit that filters the voltage response into a digital signal that can be interpreted by the microcontroller.
- Be able to measure the electrical conductivity to within acceptable accuracy while remaining submersed in the process indefinitely.

Table 3.1 shows the specifications which the EC sensor subsystem must maintain.

Specification	**Value**
Measurement	Electrical Conductivity ($S\,m^{-1}$)
Sensitivity Range	$0\,\mu S\,cm^{-1}$ - $20\,000\,\mu S\,cm^{-1}$
Accuracy	+/- 50 uS/cm
Total Lifespan	6 Months
Use Lifespan	100 Hours Intermittent Operation
Weight	Under 1lb.
Operating Temperature	10 °C - 35 °C
Max. Operating Voltage	12 V
Max. Operating Current	100 mA

Table 3.1: Specifications for Electrical Conductivity Sensor

According to the specifications for the electrical conductivity sensor in the previous subsection, the task of finding an appropriate sensor to use in this project is able to begin. First, the hydroponics team considers the possibility of constructing the sensor using more basic materials. It is ultimately decided, however, that a commercial probe should be purchased instead. This decision was made because the nature of this type of probe makes it very susceptible to minute defects. Only extremely accurate manufacturing processes are able to create acceptably accurate sensing equipment for this task.

The commercial vendor that has been decided on for supplying the electrical conductivity sensor is known as Atlas Scientific. Atlas Scientific is a company which sells many different types of sensors that are mainly focused on the measurement of fluid properties, and they have made available many testing kits and embedded chips which can be used to simplify the interfacing of probes with microcontrollers greatly.

Table 3.2 below shows an itemized list of the parts to be used in developing the hydroponics prototype with this particular subsystem. All three components in this particular subsystem are sold by a company known as Atlas Scientific, who specializes in sensor technology for use in embedded systems.

Part	Description	Cost
Atlas Scientific Pre-Assembled Female BNC	The BNC connector links the electrical conductivity probe with the microcontroller	$8.00
Atlas Scientific ENV-40-EC Probe	A conductivity sensor for use with a BNC connector	$79.14
Atlas Scientific EZO Conductivity Circuit	An embedded circuit that brings the probe readings into UART interface	$43.00

Table 3.2: Parts for the Electrical Conductivity Sensor Subsystem

This probe and circuit design combination have no problem fitting within the specifications that have been designated for this subsystem. The probe exceeds the precision of measurements that are necessary, and operates within all of the given parameters. The Atlas Scientific conductivity probe that has been selected also is among the least expensive conductivity sensors that the design team has found.

After researching the different methods of electrical conductivity measurement, the final EC probe that has been selected is a low cost lab electrical conductivity sensor that is protected with a sheathe of epoxy resin. The particular sensor version that is needed for this project is the K = 0.1 variant, because this probe will operate in drinking water conductivity ranges.

The sensor will be mounted and installed coming out of the hydroponics device enclosure. There are fittings that can be purchased such as the FC50P of FC75 [9], but this will be unnecessary for the hydroponics system design. A less robust method will be easier to implement in the prototype, and the project can be customized further in this way.

The particular installation of the sensor according to the datasheet given by Atlas Scientific shows that there are only two wires connecting the probe to the electrical conductivity circuit. It does not matter which polarity these wires are plugged into the device, because the output voltage is sent as an AC signal. Note that the probe must be calibrated before use in the process by using reference fluids that contain known electrical conductivity values.

The circuit diagram that can be used as a reference design is shown below in Figure 3.3. It can be seen that the circuit only needs to communicate to the microcontroller with two digital input/output lines. The datasheet has documentation for using the device with I2C, SPI, or UART interfacing methods.

One precaution to note with the use of the electrical conductivity sensor is that it is an

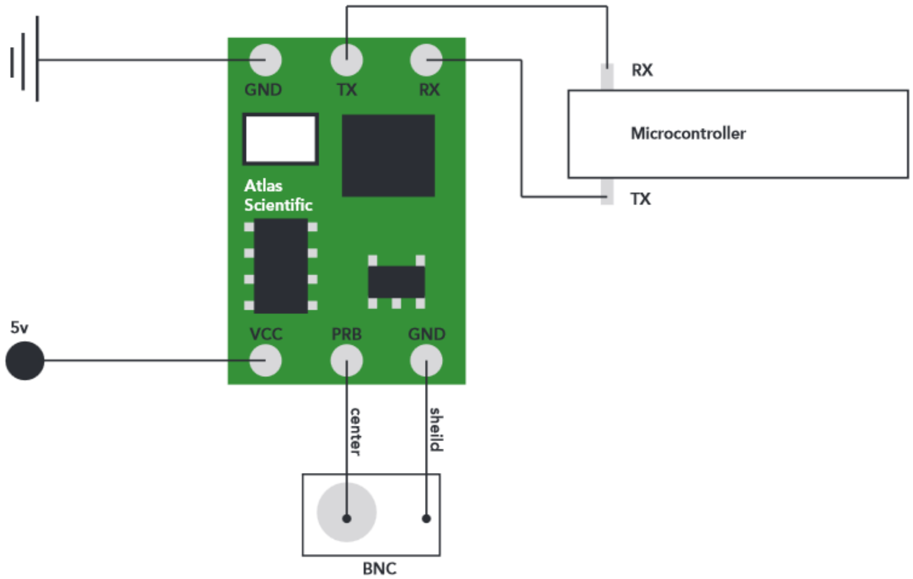

Figure 3.3: Schematic Diagram of the Atlas Scientific EC Meter [11]. *Consent to reproduce figure requested*

active device which will disrupt the function of other electrically sensitive devices that are operating in the same substance. An easy way to solve this problem is to only run the various sensors one at a time. This is not a problem for the hydroponics design specifications because each sensor reading takes place many minutes apart from each other sensor reading.

3.3.2 PH Sensor

The pH sensor allows the hydroponics device to routine sensor readings for the pH level, or acidity, of the water in the reservoir where the plant roots are. By measuring the pH level at regular intervals, corrections to the water's acidity can be made before it falls out of acceptable ranges for a healthy plant's growth.

The main objectives that this subsystem need to accomplish are:

- Measure the pH parameter of the reservoir water supply with a glass electrode probe.
- Send pH sensor voltage readings through a circuit that filters the voltage response into a digital signal that can be interpreted by the microcontroller.
- Be able to measure the pH level to within acceptable accuracy while remaining submersed in the process indefinitely.

Table 3.3 shows the specifications which the pH sensor subsystem must maintain.

Specification	Value
Measurement	pH Level
Sensitivity Range	0 pH - 14 pH
Accuracy	+/- 0.2 pH
Total Lifespan	6 Months
Use Lifespan	100 Hours Intermittent Operation
Weight	Under 1lb.
Operating Temperature	10 °C - 35 °C
Max. Operating Voltage	12 V
Max. Operating Current	100 mA

Table 3.3: Specifications for PH Sensor

Table 3.4 below shows an itemized list of the parts to be used in developing the hydroponics prototype with this particular subsystem. All three components in this particular subsystem are sold by a company known as Atlas Scientific, who specializes in sensor technology for use in embedded systems.

Part	Description	Cost
Atlas Scientific Pre-Assembled Female BNC	The BNC connector links the pH probe with the microcontroller	$8.00
Atlas Scientific ENV-40-pH Probe	A glass electrode pH sensor for use with a BNC connector	$53.21
Atlas Scientific pH Circuit	An embedded circuit that brings the probe readings into UART interface	$28.00

Table 3.4: Parts for the PH Sensor Subsystem

After researching the different methods of sensing the pH level in water, the glass electrode pH probes have been selected as most useful technique. The pH probe in particular that has been selected is a lab instrument probe from Atlas Scientific. The probe is able to be submersed in the process it is sensing for months at a time before it needs to be recalibrated or cleaned depending on the cleanliness of the solution it is in.

Mounting and installing the pH probe requires the user to first calibrate the glass electrode probe with two reference pH solutions. This gives a value that the microcontroller can use to linearly correlate the voltage signal from the pH probe with an actual pH value. The probe will be mounted next to the electrical conductivity sensor and submersed in the reservoir water in the same location. Fittings may be required to properly mount the probe to the enclosure device as well, to ensure that the probe does not come lose in any way.

The pH probe works in a very similar way to the electrical conductivity sensor does with regards to the way it is interfaced with a secondary circuit before the sensor readings finally reach the microcontroller. The circuit diagram shown below in Figure 3.4.

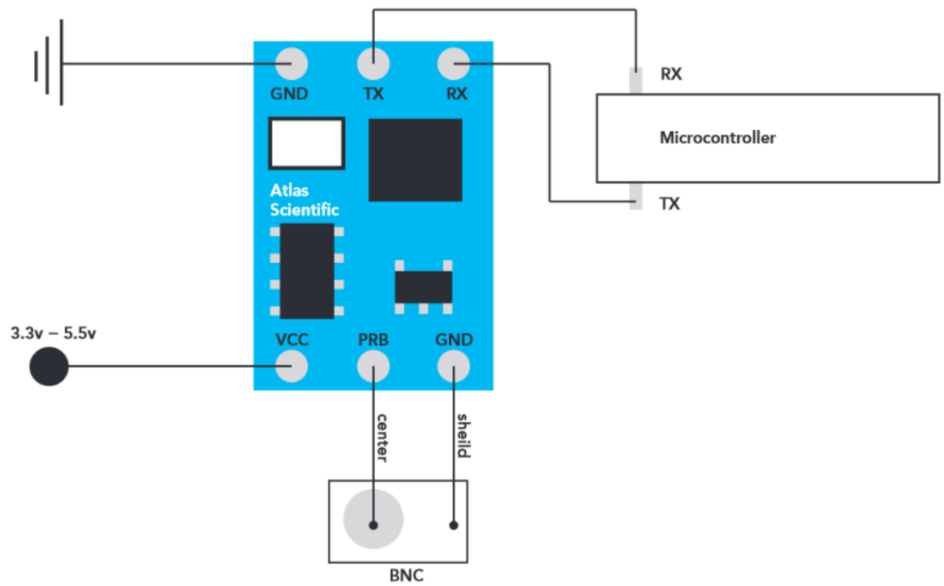

Figure 3.4: Schematic Diagram of the Atlas Scientific pH Meter [17]. *Consent to reproduce figure requested*

3.3.3 Temperature Sensor

The temperature sensor allows the hydroponics system to have knowledge about how hot or cold the water that the plant is absorbing nutrients from currently is. This is useful because if the temperature of the water exceeds certain thresholds, then the plant will not be able to grow properly. Another reason that temperature measurements of the water in the reservoir are necessary is that other sensor readings such as the electrical conductivity are affected by the temperature of the liquid, so the microcontroller will need these temperature readings to calibrate the other sensor readings. This improves the accuracy of the system, so the decisions microprocessor makes when it sends alerts to the user or adds nutrients to the water are much better informed.

The main objectives that this subsystem needs to accomplish are:

- Measure the temperature parameter of the reservoir water supply.
- Send temperature sensor voltage readings to the microcontroller to be converted to a digital signal with the built in ADCs.
- Be able to measure the water temperature to within acceptable accuracy while remaining submersed in the process indefinitely.

Table 3.5 shows the specifications which the temperature sensor subsystem must maintain.

Specification	Value
Measurement	Temperature (°C)
Sensitivity Range	10 °C - 35 °C
Accuracy	+/- 1 °C
Total Lifespan	6 Months Continuous Use
Sealing	Waterproof
Max. Operating Voltage	12 V
Max. Operating Current	10 mA

Table 3.5: Specifications for Temperature Sensor

Table 3.6 below shows an itemized list of the parts to be used in developing the hydroponics prototype with this particular subsystem. The temperature probe that has been chosen is also built by the company Atlas Scientific, who specializes in creating sensor technologies for use in embedded systems. This particular probe is designed for prolonged exposure to extreme environments, but is able to remain sensitive to temperature changes while submersed underwater.

Part	Description	Cost
Atlas Scientific ENV-TMP	A field ready temperature sensor that is protected from harsh environments with rugged shielding	$18.00

Table 3.6: Parts for the Temperature Sensor Subsystem

The temperature is an important parameter of the water in the hydroponics reservoir because it affects the readings of many other sensing devices and other electrical component's performance specifications as well. In order to measure the temperature, a very simple thermistor device can also be purchased from Atlas Scientific, who is the company that also sells the electrical conductivity meter and pH meter.

The wiring of the temperature sensor is even simpler than the other sensors, because it does not need to be connected to a filter circuit. The built in ADC systems of the chosen microprocessor for this hydroponics design will adequately convert the analog values that this temperature sensor outputs, and interpret these values for the microprocessor to use. A reference diagram of the wiring for this temperature probe circuit is shown below in Figure 3.5.

These values can be used in other functions which will recalibrate the electrical conductivity sensor, or the light level sensor which is also sensitive to temperature changes.

The temperature probe will be mounted and installed onto the device enclosure next to the electrical conductivity sensor and the pH sensor. As long as the stainless steel sheathe and epoxy sensor coverings are not damaged, the probe itself will not need any maintenance during the life of the prototype, due to the devices durability.

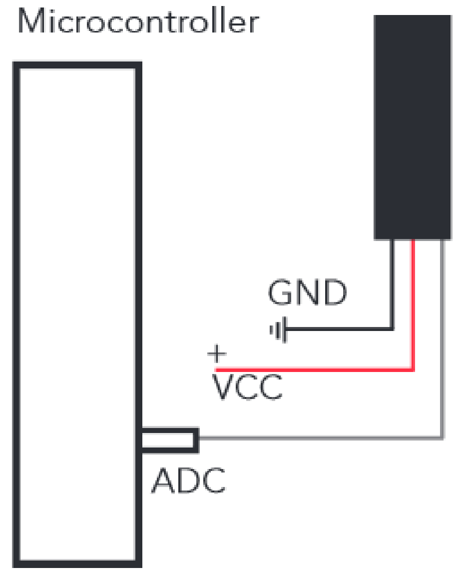

Figure 3.5: Schematic Diagram of the Atlas Scientific Temperature Meter [10]. *Consent to reproduce figure requested*

3.3.4 Light Sensor

The light sensor allows the software of the hydroponics device to use day and night cycles in the diagnostics of the other sensor data, as well as analysis of the plants growth history. A simple photodiode is used to measure the light on the device enclosure, allowing the device to be able to tell when it is day time and make decisions based on that information.

The main objectives that this subsystem needs to accomplish are:

- Measure the current light level around the plant and make inferences about the growth conditions of the plant's current location.
- Send phototransistor sensor voltage readings to the microcontroller to be converted to a digital signal with the built in ADCs.
- Be able to measure the light level to within acceptable accuracy while remaining exposed to the sunlight and weather for extended periods of time.

Table 3.7 shows the specifications which the phototransistor sensor subsystem must maintain.

Specification	Value
Measurement	Light Intensity (°C)
Total Lifespan	6 Months Continuous Use
Sealing	Waterproof
Max. Operating Voltage	12 V
Max. Operating Current	10 mA

Table 3.7: Specifications for Temperature Sensor

Table 3.8 below shows an itemized list of the parts to be used in developing the hydroponics prototype with this particular subsystem. The temperature probe that has been chosen is also built by the company Atlas Scientific, who specializes in creating sensor technologies for use in embedded systems. This particular probe is designed for prolonged exposure to extreme environments, but is able to remain sensitive to temperature changes while submersed underwater.

Part	Description	Cost
Vishay Silicon NPN Phototransistor	A simple phototransistor sensor.	$0.50

Table 3.8: Parts for the Phototransistor Subsystem

The function and implementation of the light sensitive phototransistor is very similar to the temperature sensor. One reason they are so similar, in fact, is that they are both simply transistors that are linked to the analog pins of the microcontroller.

The transistor will need to be mounted within a transparent enclosure that can protect the device from condensation or actual water damage, while also allowing light to penetrate into the transistor base collector junction for the operation of the device to not be impeded. This can easily be accomplished by mounting it onto the top of the device enclosure itself.

3.3.5 Water Supply Valve and Sensor

One of the requirements to run a deep water culture hydroponics system is to have a deep reservoir of water for the plant roots to sit in and drink nutrients from. The water supply valve and sensor assembly subsystem have the task of ensuring that the water fills the reservoir properly, and also alerts the user whenever the water level sinks past a certain threshold for any reason.

The main objectives that this subsystem needs to accomplish are:

- Provide a mechanical attachment point for a common hose to be screwed onto the reservoir.
- Use a valve assembly to allow the reservoir to fill itself up without overflowing.

- Create drainage holes to control water overflow in the event of rain or other outside floods.
- Send water level data to the microcontroller through with a water level switch.

Table 3.9 below shows the specifications which the water supply valve and sensor subsystem must maintain.

Specification	Value
Accuracy	+/- 1 Liter
Min. Flow	$1\,\mathrm{L\,s^{-1}}$
Total Lifespan	6 Months Continuous Use
Sealing	Waterproof
Max. Operating Voltage	12 V
Max. Operating Current	10 mA

Table 3.9: Specifications for Water Valve and Sensor

Table 3.10 below shows an itemized list of the parts to be used in developing the hydroponics prototype with this particular subsystem.

Part	Description	Cost
Water Level Float Switch	A simple float switch that can be used to detect the water level with a microcontroller	$5.00
Kerick Valve	This mini float valve can be mounted to the reservoir and connected with a hose to constantly fill the water supply	$8.37

Table 3.10: Parts for the Water Supply Valve and Sensor Subsystem

The water level of the hydroponics system is one of the only subsystems in the device which can be controlled easily with purely mechanical means, through the use of valves and drainage holes. The subsystem design is improved with a low cost but reliable water level sensor which will enable the hydroponics device to send the user alerts when the water level becomes to low. This event might occur if the water supply hose became disconnected at some point from the device for an extended period of time.

The water level sensor can either be mounted directly to the reservoir or along with the device enclosure, but it must be physically located at the precise depth that the water should be considered filled to. This would correspond with a liquid volume of about 20 gallons, or when the reservoir itself is nearly topped off.

The water valve must be mounted directly to the water reservoir for the prototype's design in order to simplify the mechanical construction. This is a sacrifice to the overall portability of the hydroponic system, but it is necessary to create a well designed enclosure. The valve must be installed and sealed properly through the side of the reservoir, and care must be taken to ensure that no leaks are happening so that excess water is not wasted.

3.3.6 Peristaltic Liquid Pump

One of the most important features of the proposed hydroponics system is the automation of the process where a user would add nutrient or pH buffer solution to the water after they measure these parameters of the water. The best way to add liquid solutions to the water reservoir with the control of a microprocessor is to use electrical pumps. Each liquid that needs to be added to the water reservoir will need its own motor so that varying amounts can be added independently.

The principal liquid pump design that has been decided upon for this project is called a peristaltic pump, which can pump liquids and gases in a manner similar to the way that the human digestive system operates. Peristaltic pumps can also work with DC motors, making them easy to interface with microcontrollers and minimally impacting the financial budget.

The main objectives that this subsystem needs to accomplish are:

- Deliver liquid solutions from containers outside the reservoir to the reservoir interior.
- Be able to send precise amounts of liquid solution that can be controlled easily with the microcontroller.
- Be able to use a simple DC motor and common nylon tubing for the transfer process and pump assembly.

Table 3.11 shows the specifications which the peristaltic pump subsystems must maintain.

Specification	**Value**
Medium	Liquid
Motor	DC
Max. Operating Voltage	12 V
Max. Operating Current	500 mA
Flow Rate	10 - 50 mL min^{-1}
Lifespan	50 Hours Intermittent Use
Max. Weight	2lb.

Table 3.11: Specifications for Peristaltic Pumps

Table 3.12 below shows an itemized list of the parts to be used in developing the hydroponics prototype with this particular subsystem. The main components of this subsystem are the two peristaltic pumps which will be used to pump liquid nutrients and pH buffer into the water reservoir. These pumps were chosen because of the simplicity of their design, minimal impact on the project's financial budget, and ease of ordering from a supplier's website.

Tubing is a secondary component that will need to be considered when designing this subsystem. The tubing will need to be routed from the device enclosure where the nutrients fluid and pH buffer fluid are stored, to the water reservoir where the plant roots will absorb the nutrients.

The final considerations with regard to materials consumed with this subsystem are mounting brackets and electrical wiring. Ultimately they will not be itemized into the financial budget, but listed instead as a group of miscellaneous costs.

Part	**Description**	**Cost**
Thomas SR 10/30 DC Peristaltic Pump	This pump is used to move specific amounts of fluids through miniature tubing, commonly used for delivering small amounts of chemicals	$56.94
Nylon Tubing	Tubing to create a pathway from the device enclosure to the water reservoir.	$0.18 per foot

Table 3.12: Parts for the Peristaltic Pumps Subsystems

The peristaltic pump has been considered to be the optimal type of pump to use for this hydroponics design when transporting small but precise amounts of liquid from outside the device enclosure to the interior of the water reservoir. In order to satisfy the needs of the current system's design, two peristaltic pumps must be used in parallel with each other so that varying amounts of nutrient solution and pH buffer solution can be added to the reservoir independently of each other.

The installation of these pumps will take place in the device enclosure, next to the other diaphragm pump as well as the microcontroller and sensor printed circuit boards. Clear nylon (or another type of plastic) tubing will run from below the device enclosure, where the containers of nutrient solution and pH buffer are located, up through the enclosure and out into the water reservoir by the various sensors. The tubing will need to go far enough into the water reservoir to not directly affect the sensitive laboratory sensors. Figure 3.6 shows the dimensional multiview drawing of the Thomas SR-VDLC10/30 peristaltic pump.

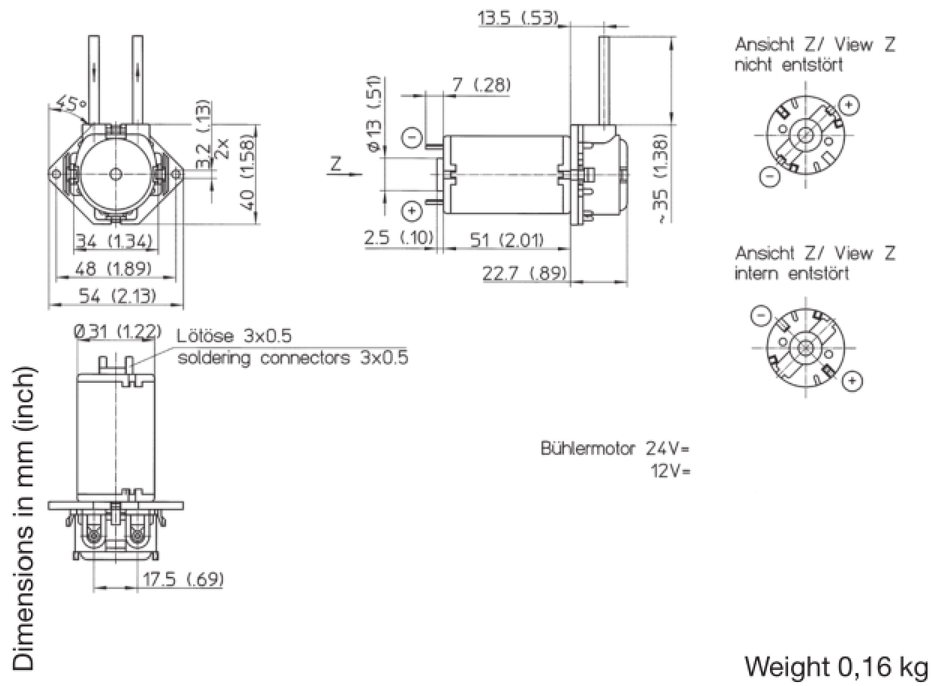

Figure 3.6: Multiview Schematic Drawing of SR10/30 DC Straight Flange Pump [20]. *Consent to reproduce figure requested*

3.3.7 Oxygenation Pump and Filter

Another important task that needs to be accomplished in this hydroponics system is to oxygenate the water in the reservoir that the plant is absorbing nutrients from. As discussed in the research portion of this design document, oxygen must be present in the water so that the roots of the plant can breathe instead of rotting and preventing the plant from growing. This is not completely necessary for all types of hydroponics where certain stages of the process will automatically oxygenate the water supply, but it is necessary in the Deep Water Culture process that this hydroponics system is designed with.

The principal air pump design that has been decided upon for this project is called a diaphragm pump, which can pump gas in a manner similar to the way that lungs operate. Diaphragm pumps can also work with DC motors, making them easy to interface with microcontrollers and minimally impacting the financial budget.

The main objectives that this subsystem needs to accomplish are:

- Be able to pump air continuously into the reservoirs deepest depth.
- Make use of common nylon tubing and a low cost DC motor to power the pump with the capability to run at all times for months.

- Use a filter that can properly oxygenate the water as air is pumped through it.

Table 3.13 shows the specifications which the diaphragm pump subsystem must maintain.

Specification	Value
Medium	Air
Motor	DC
Max. Operating Voltage	12 V
Max. Operating Current	500 mA
Max Flow Rate	500 - 1000 mL min^{-1}
Lifespan	6 Months Continuous Use
Max. Weight	2lb.

Table 3.13: Specifications for Air Pump and Filter

Table 3.14 shows an itemized list of the parts to be used in developing the hydroponics prototype with this particular subsystem. This is the single biggest subsystem in the hydroponics system design with regard to power consumption, as the air pump mechanism will need to be running continuously and at all times.

The main components of this subsystem are the diaphragm pump that does the work of pumping the air into the higher pressure of the reservoir, and the air filter and air stone combination device that diffuses the air into the water while also filtering out any undissolved solids contained in the water reservoir.

The secondary component that needs to be considered for this subsystem is the nylon tubing that will start from the enclosure, where the diaphragm pump is mounted, and continue to the bottom center of the water reservoir, where the air stone and air filter are mounted.

Part	Description	Cost
Thomas 3003 VD LC Diaphragm Pump	This miniature diaphragm pump uses a low cost DC motor to move air through nylon tubing	$56.94
Hydro II Sponge Pro Filter - Up to 20 gallons	An Air Stone/Air Filter Combination	$9.94
Nylon Tubing	Tubing to create a pathway from the device enclosure to the water reservoir.	$0.18 per foot

Table 3.14: Parts for the Oxygenation Subsystem

The air pump system is primarily driven by a miniature DC diaphragm pump that is manufactured by the company Thomas. This pump is able to pump a steady stream of air from the enclosure directly into the bottom of the hydroponics system reservoir. It is an oil-less pump as well, meaning that no maintenance is required for the continuous use of this device.

The diaphragm pump motor will be mounted next to the two peristaltic pumps at the bottom of the device enclosure. a clear plastic nylon tube will need to run alongside the peristaltic pump tubes and be routed into the bottom of the reservoir and in the center where the air filter and air stone is located. The air filter and air stone take this incoming air and squeeze water into the porous filter substance, which causes dissolved air to permeate the water flowing through the filter system. The air filter and air stone need to be mounted as close to the center and under the plant as possible. This will ensure that an optimal amount of liquid is being circulated throughout the device and that enough dissolved oxygen is being added to the water.

Mounting of these devices will be accomplished with screws and holes, and since they are placed in a environmentally protective enclosure, there is no need to worry about water damaging the components themselves. Figure 3.7 shows the dimensional drawing for the diaphragm pump to be used in this device. Notice that it is quite small compared to the other two sensors, and only needs one tube output to function correctly.

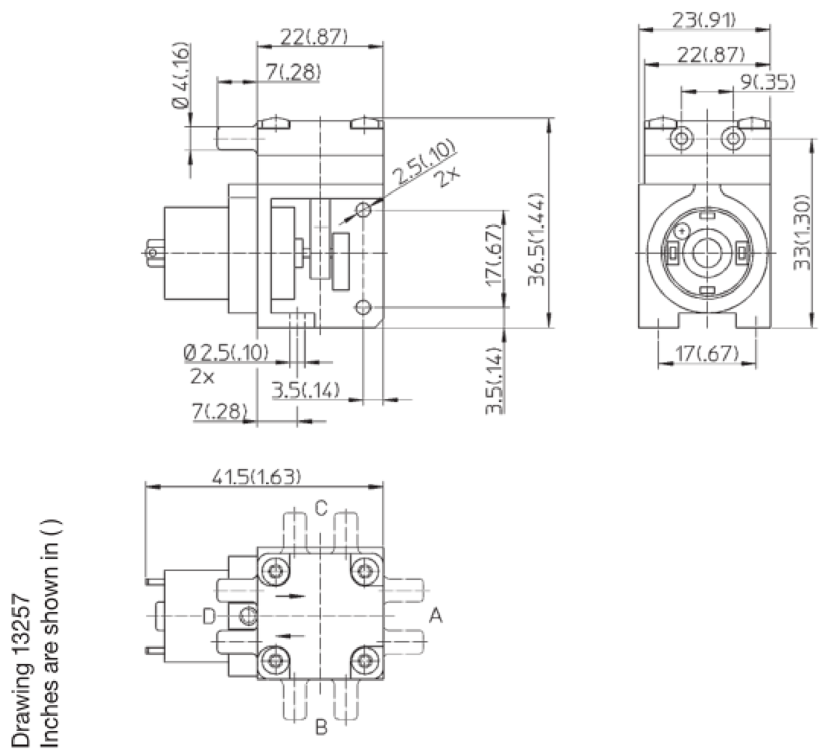

Figure 3.7: Multiview Schematic Drawing of 3003VDLC Diaphragm Pump [6]. *Consent to reproduce figure requested.*

3.3.8 Device Enclosure

The enclosure being referred to here is the protective structure that will be used to mount the printed circuit board and motor components inside. It will server to isolate the sensitive electrical components from the environment, and it will also bring structure and compartmentalize the different components of the design for a professional looking prototype.

The main objectives that this subsystem needs to accomplish are:

- House and protect all of the electrical components, while keeping all sensitive circuits out of reach of water splashes that might otherwise damage them.
- Be portable enough to switch from multiple different sizes of deep water reservoirs.
- Be made of transparent material so that the interior components can be seen during prototype demonstrations.
- Display any important usage messages or branding information.
- Be made of inexpensive though durable materials with future manufacturing processes in mind.

Table 3.15 shows the specifications which the device enclosure subsystem must maintain.

Specification	**Value**
Sealing	Rainproof
Max. Weight	5lb.
Lifespan	1 Year

Table 3.15: Specifications for Device Enclosure

Table 3.16 below shows an itemized list of the parts to be used in developing the hydroponics prototype with this particular subsystem.

Part	**Description**	**Cost**
FIBOX PC 17/16-L3	Cardmaster enclosure that is ideal for packaging sensor instrumentation and electronics	$52.73

Table 3.16: Parts for the Enclosure Subsystem

The main functions of the enclosure is to house all of the electrical components, keep them safe and secure from outside interference like shock or weathering, and provide an appealing looking mounting system for the device. For demonstration purposes of the prototype, transparent enclosures have been considered in order to allow people to look at the inside functions of the device as it operates.

The device is mounted onto the side of the plant reservoir and lid structure, with an enclosure containing the sensors overhanging into the interior side of the water reservoir. The lid of the reservoir then folds over to block any sunlight from reaching into the reservoir, which could spur the growth of algae that will harm the growth of the other plants.

The main enclosure that has been chosen as a reference to base the prototype enclosure off of is the FIBOX Cardmaster enclosure system. They have built a specialty enclosure system that is designed for use with sensitive lab equipment and instrumentation sensors, which fits the hydroponics system application perfectly. In order to incorporate tubing and the sensor probe overhang section, additional plastic will have to be attached to the device, and holes will have to be drilled at various points on the enclosure.

Figure 3.8 shows the dimensional multiview drawing which is used for the aid of modeling what the prototype design is going to look like.

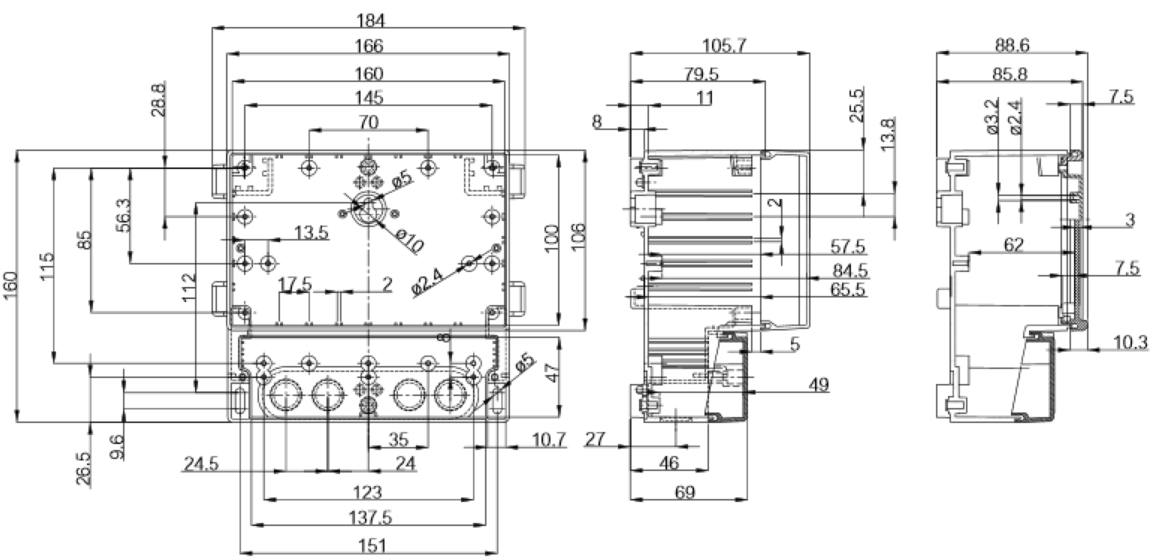

Figure 3.8: A Multiview Schematic Drawing of FIBOX Enclosure [15]. *Consent to reproduce figure requested.*

3.3.9 Plant Reservoir and Lid

The plant reservoir referred to in this paper is the main plastic bucket which contains all of the water that the plant roots are sitting in. The main consideration for this plant reservoir is to use something that looks professional, while also being easily modifiable so that the device enclosure and other valves could be easily mounted to the bucket. The design element for this subsystem is to create a lid to this container which plant soil buckets can be mounted on top of with their roots hanging into the water. The lid also needs to maintain as solid of a seal from outside light as possible in order to minimize the light that comes into the reservoir.

The main objectives that this subsystem needs to accomplish are:

- Hold an adequate volume of water for use with a deep water culture hydroponics system.
- Provide support for a large amount of plant weight to bear down onto the lid.
- Provide space for the device enclosure to be mounted on the side.
- Be easily modifiable so that drainage holes and fittings can be incorporated into the reservoir with ease.
- Display important messages or prototype branding information for demonstration purposes.

Table 3.17 shows the specifications which the reservoir and plant subsystem must maintain.

Specification	**Value**
Sealing	99% Light Blocked
Max. Weight	20lb.
Lifespan	1 Year
Plant Locations	2

Table 3.17: Specifications for Plant Reservoir and Lid

Table 3.18 below shows an itemized list of the parts to be used in developing the hydroponics prototype with this particular subsystem.

Part	**Description**	**Cost**
Botanicare 20 Gallon Reservoir Bottom Only	A reservoir built with hydroponics in mind, with front and side bulkhead ports to accommodate external pumps and sensors.	$46.54
Botanicare 20 Gallon Reservoir Lid	A reservoir lid with built in access port to remove the need to take off the lid when inspecting the interior.	$32.70
Net Pots (Growing Baskets)	5.5 inch diameter pots designed for roots to be able to reach through the mesh sides.	$1.00 each
Hydroton Pebbles (Growing Medium)	10 Liters of pebbles which work to support the roots of the plant through the growth process.	$10.00

Table 3.18: Parts for the Reservoir Subsystem

The main functions of the water reservoir and lid system are to provide a stable support system for the rest of the device, and also be an adequate housing for various sensors. The reservoir must also be easily modifiable so that valves and drainage holes can easily be added to the sides of the device, and the lid must be easily modifiable so that it can be shaped for the device enclosure to fit into.

The reservoir that has been chosen for use in this project is manufactured by a company specifically for use in hydroponics, and it is well suited to the task of holding water and mounting scientific equipment to. The volume that the liquid reservoir can sustain is up to 20 gallons, and a dimensional drawing of the reservoir is shown below in Figure 3.9.

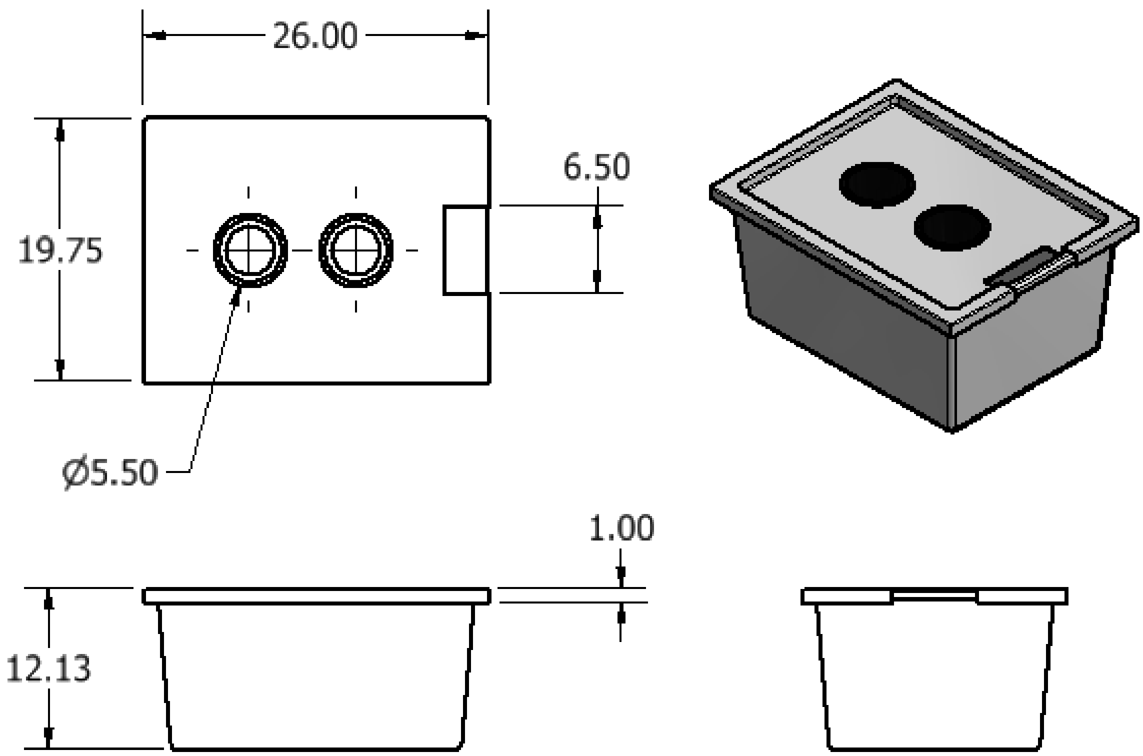

Figure 3.9: Dimensions of the Hydroponics Reservoir. (Inches)

The lid to the hydroponics system needs to be shaped and cut out so that the device enclosure fits tightly onto the container while having access to the reservoir water. The seal between the two objects must be tight enough so that a minimal amount of light can reach into the reservoir and cause algae to grow. Figure 3.9 shows the dimensions that the lid needs to be cut down to in order to fit the enclosure as well as the two plant net pots.

3.3.10 Solar Panel, Battery, and Charge Controller

In an effort to create a hydroponics system that promotes sustainability and energy independence, the solar system is being designed to charge a battery that the device can be run off of completely. The main factors driving the architecture decisions with regard to the solar system are generating the minimal amount of power that remains adequate for the device to run on, and to use parts which accomplish this task with a minimal impact on the financial budget.

The main objectives that this subsystem needs to accomplish are:

- Allow the device to run independently of any outside power sources.
- Have a modular power system to allow the use of a normal AC power source, or the use of the solar power charging system.
- Design a charge controller circuit that can efficiently couple a solar panel to the chosen battery system.

Table 3.19 shows the specifications which the solar panel and battery subsystem must maintain.

Specification	**Value**
Operating Voltage	12V
Continuous use lifespan	1 year
Battery Capacity	20Ah
Solar Panel Power Output	20W

Table 3.19: Specifications for Solar Panels and Battery

Table 3.20 below shows an itemized list of the parts to be used in developing the hydroponics prototype with this particular subsystem.

Part	**Description**	**Cost**
Panasonic LC-X1220P Battery	A valve regulated lead acid battery	$61.00
Multicomp MC-SP20-GCS	A solar panel	$187.62
Solarland SLB-0103	Solar panel mounting system	$76.00
SolarMagic SM3320-BATT-EV	High efficiency photovoltaic charge controller	$159.08

Table 3.20: Parts for the Solar Power, Battery, and Charge Controller Subsystem

Battery - The design conditions under consideration for the battery design are listed below. These specified conditions were taken into account while choosing the right battery design for the automated hydroponics system.

Design conditions:

- Battery Capacity in Units of Ah or Wh
- Nominal Voltage Rating
- Affordability to Minimize Impact on Financial Budget

The battery is important for the power system of the hydroponics system because the system is solar powered and needs have power during times of no sunlight. A lead-acid battery was chosen as the type of battery used for the design to meet the conditions listed. The battery should have a capacity of 20 Ah which is enough power for the device to sustain power for approximately 24 hours. The battery provides the power for the entire hydroponics system which means that it must be reliable. Additionally, the battery should be 12 volts because the system is using 12 volt pumps. Lead acid batteries are heavier than other types of batteries. Portability is not the main concern of this project and so the battery's dimensions and weight are irrelevant in this case. The dimensions are shown in the schematics below of the Panasonic LC-X1220P lead acid battery which has the specifications that the system requires. The Panasonic LC-X1220P is a 12 volt battery with a 20 Ah capacity. This battery will meet the requirements for use in the power system for the hydroponics controller.

This battery will be located in the power circuit with the battery being the load for the solar panel source. There is also a charge controller placed in the circuit to determine when the battery has full power to protect against overcharging. The operation of this circuit is essential to maintain stability of the power system. If the battery is overcharged or goes into a deep discharge then it could be damaged. To protect against these problems the battery needs to have a big enough capacity so that it does not fully discharge and also the charge controller can keep the battery from being overcharged. There are no other problems that can happen to the battery past these two conditions, which makes regulation of the battery's operation fairly simple.

The lead acid battery is physically mounted onto the hydroponics system somewhere underneath the microcontroller enclosure. It could possibly be attached to the controller unit with plastic clamps to hold it in place. This would allow for easy access to the battery for removing the battery when it eventually malfunctions or dies. It would also be located in close proximity to the enclosure for the microcontroller so that the charge controller circuit could be located with the microcontroller. This concept of location makes sense for the hydroponics controller unit to allow for a compact device without having too many individual parts. The lead acid battery used for the design will add to the total weight of the hydroponics controller. This is another good reason to have the battery on the bottom of the unit because if it were to be mounted high then the hydroponics controller could tip over particularly when the reservoir is not filled with water. Figure 3.10 shows a multiview schematic drawing for use in designing the subsystem.

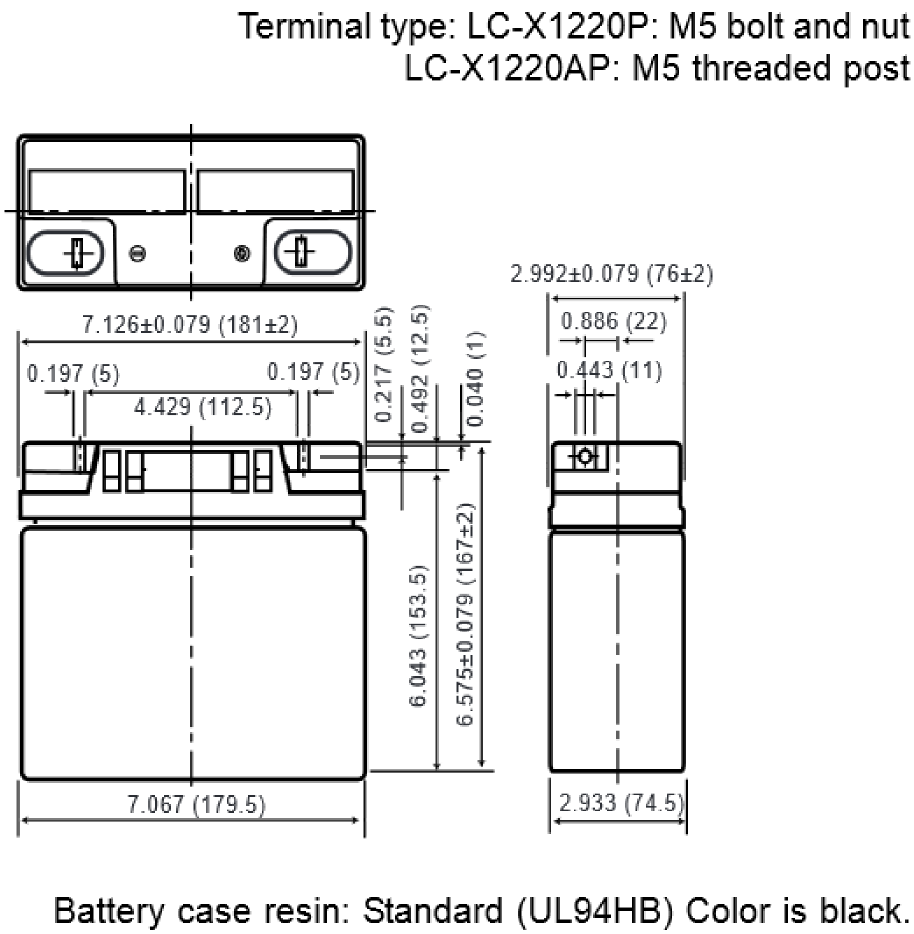

Figure 3.10: A Multiview Schematic Drawing of the Panasonic LC-X1220P [12]. *Consent to reproduce figure requested.*

Solar Panel - The design conditions under consideration for the solar panel design are listed below. These conditions were taken into account while choosing the design for the hydroponics automated system.

Design Conditions:

- Power Output in Watts
- Compact Size
- Affordability to Minimize

The solar panel is another critical component for the project because it is supplying the power to drive the pumps and motors for the hydroponics system. The solar panels need to be matched correctly with the battery that used for the power system to charge it completely, which is a 12V and 20 Ah battery in this case. Additionally, the solar cell array needs to be at least 20 Watts to fully charge the batteries during sunlight hours. It must produce enough power to keep the battery from discharging more than 50% of its full charge because this would greatly reduce the life of the battery. The dimensions of the solar panel will be relatively small at about .5m tall and .3m long. This is shown in the schematic diagram below containing the Multicomp MC-SP20-GCS 20 Watt solar panel. The Multicomp MC-SP20-GCS meets the requirements for the power system for the hydroponics controller. This solar panel is able to produce enough energy to fully charge the lead-acid battery during the day because it is a 20 Watt solar panel with a 20 Ah battery.

Solar panel mounting can be done with brackets that hold the solar panel in place and keep it from moving. A solar panel must be put onto a structure that is sturdy enough to hold the PV panel in place without wind or rain moving it around. All solar panels are mounted in some way using similar methods. The solar array can be mounted on the roof of a house to get direct sunlight or mounted on a simple structure built out of cheap metals such as aluminum. The main objective is to get the solar panel placed in a position where it can receive the maximum amount of direct sunlight during the day. Because of the small size of the solar panel used for the hydroponics controller the solar panel can be placed on mounts on the ground. There are many products available for ground mounting solutions. The Solarland SLB-0103 solar panel mounts are perfect for small solar panel mounting like is needed for the hydroponics controller. These small mounts are typically used for mounting on an RV, boats, or small structures. Included in the design for these mounts are brackets that attach to a hinged metal frame that tilts the PV panel to the desired angle.

This solar panel is connected into the power circuit which contains the solar panel, battery, and charge controller used for the power system of the device. The main objective for the power system is to simply provide enough power using solar energy from the sun to run all of the operations of the device for all day. This requires the solar panel to be large enough to fully charge the battery during approximately 8 hours of sunlight time and the battery must have a large enough capacity to power the device all of the other times.

Charge Controller - The design conditions for the charge controller under consideration are listed below. These condition were taken into account when choosing a design for the charge controller.

Design Conditions:

- State of Charge Management
- Maximum Power Transfer
- Efficiency

The charge controller is a vital part of the power system because it is needed to keep the battery from overcharging. It is located in between the solar panel and the battery and therefore could be attached to hydroponics device for convenience. The circuit must also include maximum point power tracking to obtain the maximum power transfer from the source. This is a complex circuit that includes inputs to the microcontroller for communicating with the SOC of the battery and also outputs for changing the state of the charge controller to keep the battery from overcharging.

A DC/DC converter stage is required in the circuit to transfer the power from the solar panel to the load. It is used in the charge controller circuit to step up or step down the voltage for the power coming from the solar panel into the battery. A circuit diagram for the DC/DC converter used in the AN-2121 Solar Magic SM3320-BATT-EV charge controller reference design is shown in Figure 3.11 below. Our design of the DC/DC converter for the charge controller can be similar to the one in the diagram below. The goal for the DC/DC converter stage is to change voltage level coming into the circuit to a different value.

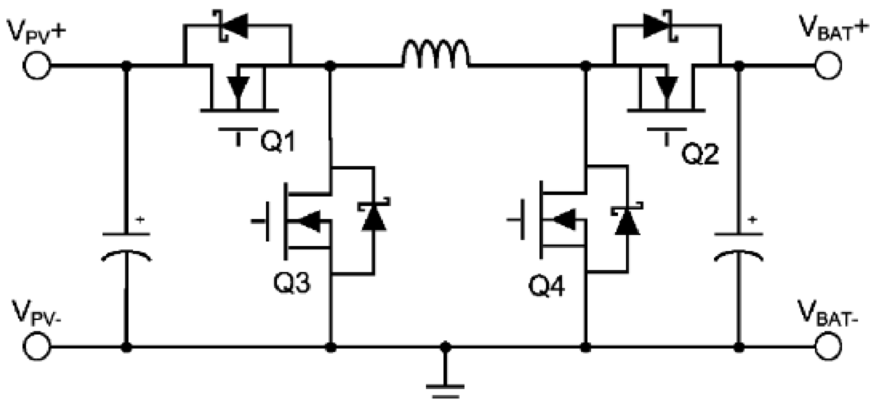

Figure 3.11: DC/DC Converter Stage of Charge Controller [19]. *Consent to reproduce figure requested.*

In addition to a DC/DC converter, a start-up circuit is required to make the duty cycle high enough that creates a flow of current to the battery when the solar panel voltage is lower than the battery voltage. This is an essential part of the charge controller to keep the charge going through any condition. The way that it works is the circuit is on when the anode of D101 and the cathode of D100 are at 5V and it is disabled when the node is set to 0V. This node is connected to a pin on the microcontroller where the microcotroller can enable or disable the circuit by using the pin as an output. The start-up circuit from in the AN-2121 Solar Magic SM3320-BATT-EV charge controller reference design is shown in Figure 3.12 below which displays the circuit diagram.

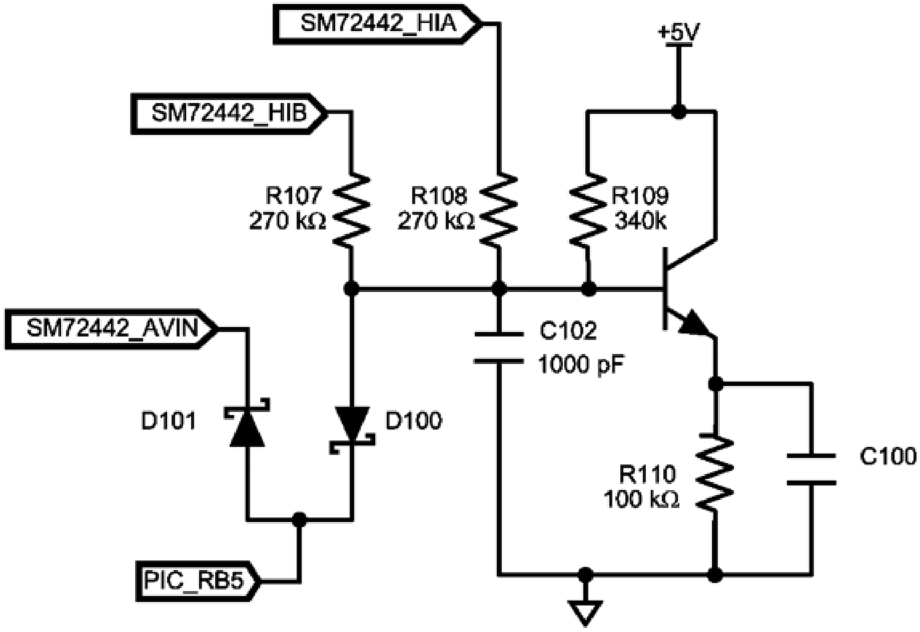

Figure 3.12: Start Up Stage for Charge Controller [19]. *Consent to reproduce figure requested.*

The charge controller is implemented using programming software that is embedded in the microcontroller which can read the state of charge (SOC) of the battery and react accordingly. This accomplished by reading inputs into the microcontroller from the charge controller circuit. Listed below in Figure 3.13 is an example of the flow chart that is needed to perform the charge controller reaction.

The microcontroller should be able to evaluate the solar panel and battery voltages during the start-up of the device. Then, the microcontroller can enable the charge by releasing the RESET line of the SM72442 chip only if the voltage values are right. Functions are used by the microcontroller to perform the required tasks of the charge controller. One function for example is used to sense the battery's voltage that is coming through the microcontroller's A/D converter with a three bit digital signal that correlates to the status of the battery's SOC. These functions are used for software on the embedded system to effectively dictate the charge controller's action.

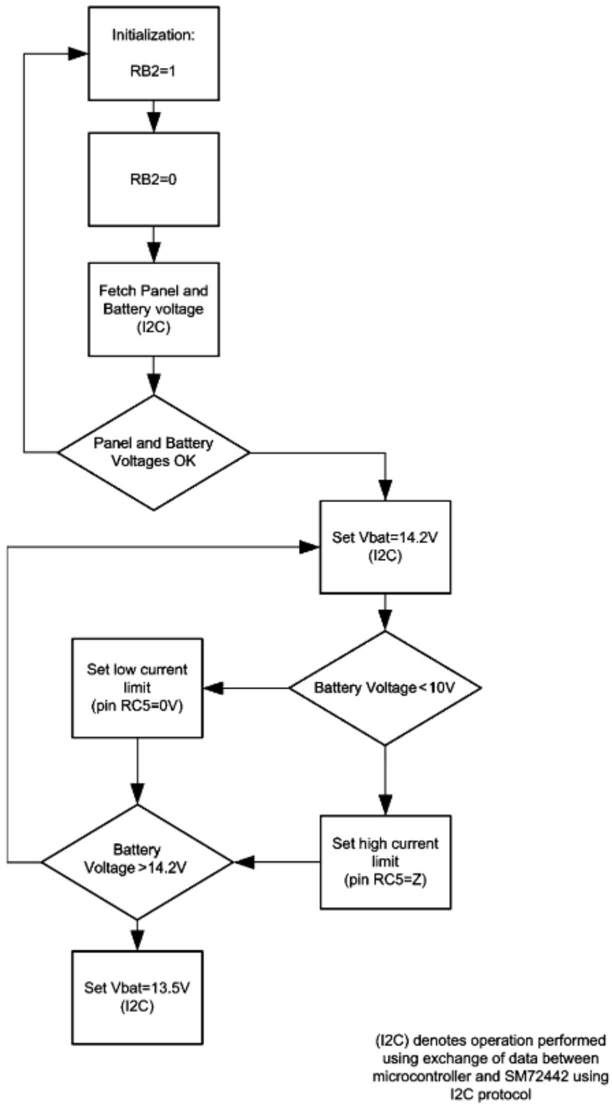

Figure 3.13: Operational Flow Chart for Charge Controller [19]. *Consent to reproduce figure requested.*

3.3.11 Wi-Fi Transmitter

The wireless communications in this hydroponics device will be maintained over Wi-Fi. The device will connect to a designated web server hosted specifically for this project.

The main objectives that this subsystem needs to accomplish are:

- Allow the hydroponics device to send alerts and updates to the user over a wireless internet connection.
- Use a low cost Wi-Fi transceiver to facilitate two way communications with a hosted web server.
- Be able to interface the Wi-Fi transceiver with the microcontroller through digital IO pins.

Table 3.21 shows the specifications which the Wi-Fi communications subsystem must maintain.

Specification	**Value**
Frequency	2.4GHz
Modulation	OFDM
Data Rate	6-54Mbps
Sensitivity	-90dBm
Maximum Power Output	15dBm

Table 3.21: Specifications for Wi-Fi Communications

Table 3.22 below shows an itemized list of the parts to be used in developing the hydroponics prototype with this particular subsystem.

Part	**Description**	**Cost**
RN-131C Wi-Fi Module	Roving Networks 802.11 WiFly GSX Module	$36.92

Table 3.22: Parts for the Wi-Fi Communications Subsystem

The hydroponics system design calls for the use of a wireless network transceiver, and the device that has been selected for this subsystem design is the Roving Networks RN-131 802.11 b/g Wireless LAN Module. It is an embedded standalone module which is will minimally affect the hydroponics project's financial budget, while also taking up very little space on the printed circuit board design. The dimensions of the RN-131 module are shown below in Figure 3.14.

In addition to taking up a minimal amount of physical space on the PCB through surface mounting, the device is very easy to interface with microcontrollers as well. The modules come shipped with preloaded software that minimizes application development

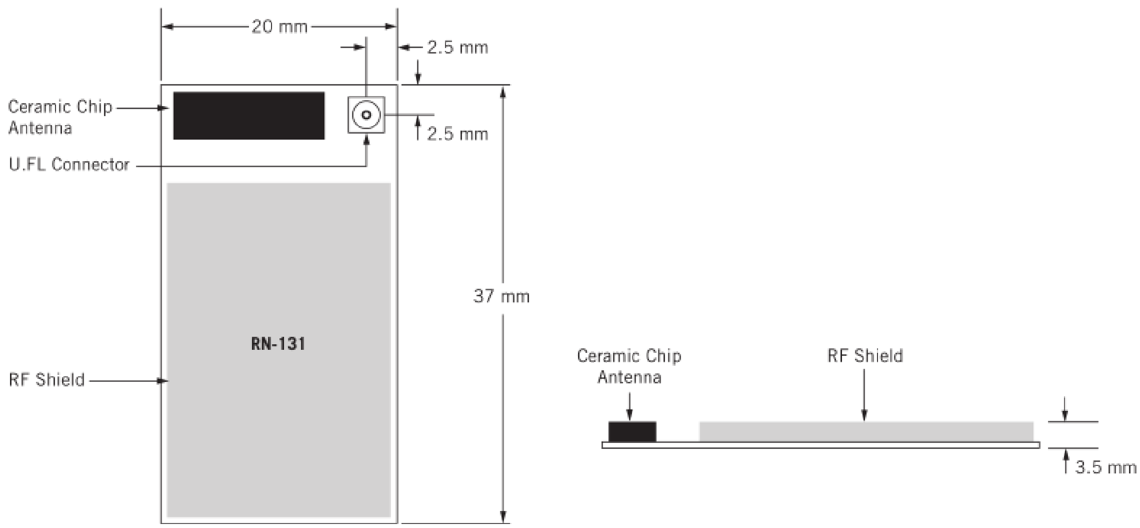

Figure 3.14: A Multiview Schematic Drawing of the RN131G Wi-Fi Transceiver [18] *Consent to reproduce figure requested.*

and is extensively documented in user manuals online. The hardware only requires four connections to run in its most basic configuration (PWR, TX, RX, and GND). Once the device has been initially configured, the RN 131 module can connect to any open Wi-Fi networks that it finds during its automated scanning process when it wakes up.

One precaution that needs to be taken is during the design of the location that the device will be surface mounted to the printed circuit board. The antenna mounted to the device needs to be clear of any nearby electrical component's interference, so an area of no activity needs to be placed around the antenna. If this cannot be feasibly achieved, then a simple antenna can be attached to the device through a simple connection and mounted further from the interference. Figure 3.15 below shows a schematic diagram of the clearance required for the antenna to work properly.

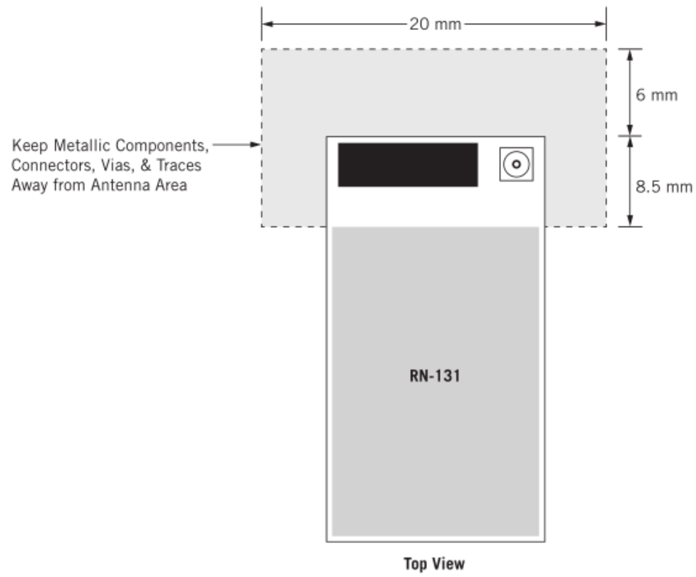

Figure 3.15: RN-131 Antenna Clearance Diagram [18]. *Consent to reproduce figure requested.*

3.3.12 Microcontroller

The microcontroller is the brains of the embedded system design. It is what gathers sensor data, controls the various motors, and makes decisions on what to communicate to the user in the event that the user needs to be notified. Eventually, the microcontroller needs to be surface mounted onto a designed printed circuit board, but, in order to assist with rapid development of the project, a development kid will be used during the initial construction of the prototype hydroponics system.

The main objectives that this subsystem needs to accomplish are:

- Process sensor data into information that can be used to make decisions about nutrient or pH buffer solution additions.
- Send communications data to the Wi-Fi module for the user to get access to over the internet.
- Interface with all of the electrical components to provide power and signal information.

Table 3.23 shows the specifications which the microcontroller subsystem must maintain.

During the initial construction of the hydroponics system, the focus will be on making sure the sensors are properly interfacing with the microcontroller, and that the programmers can start working on the software that will run the microcontroller. In order to expedite this process, a development kit will be used to be able to jump right into the

Specification	Value
Digital I/O	10
PWM Outputs	3
Analog I/O	4

Table 3.23: Specifications for Microcontroller

prototyping stage at the beginning of senior design 2.

Table 3.24 below shows an itemized list of the parts to be used in developing the hydroponics prototype with this particular subsystem.

Part	Description	Cost
Arduino Leonardo Development Kit	A first party development kit from Arduino for the Atmel Atmega32u4 microprocessor.	$24.95
Atmel Atmega32u4-MU	An 8 bit microprocessor with 16MHz clock speed.	$6.21

Table 3.24: Parts for the Microcontroller Subsystem

Being an 8bit embedded system, this microprocessor functions in a very similar way to the Texas Instruments MSP430 microprocessor that has been used as an educational tool in previous classes at University of Central Florida. This processor contains 26 total IOs, 8PWM channels, 16MHz CPU speed, and 1KB EEPROM memory size. It is possible to interface I2C, SPI, UART, and USART with this microprocessor.

In general there are many things to consider during the design of the microcontroller system, and it is difficult to pinpoint exactly what will be useful during its operation until the device is actually being programmed. The general block diagram of the different components of the Atmel Atmega32u4 CPU are shown below in Figure 3.16.

One thing to keep in consideration is the power consumption of the microprocessor. In general, when trying to minimize the power consumption of the microprocessor device, sleep and standby modes should be used as much as possible. When a device is not needed, it should be disabled, because during sleep modes some devices will still remain active. Special care needs to be taken with devices such as the ADCs, brown-out detectors, the watchdog timer, port pins, and the on-chip debug system.

Another important benefit to using this microprocessor is making use of the built in ADC. The ADCs in the Atmega32u4 processor convert an analog input voltage into 10bit digital values. This ADC 10bit value is then stored in the ADC data registers, ADCH, and ADCL.

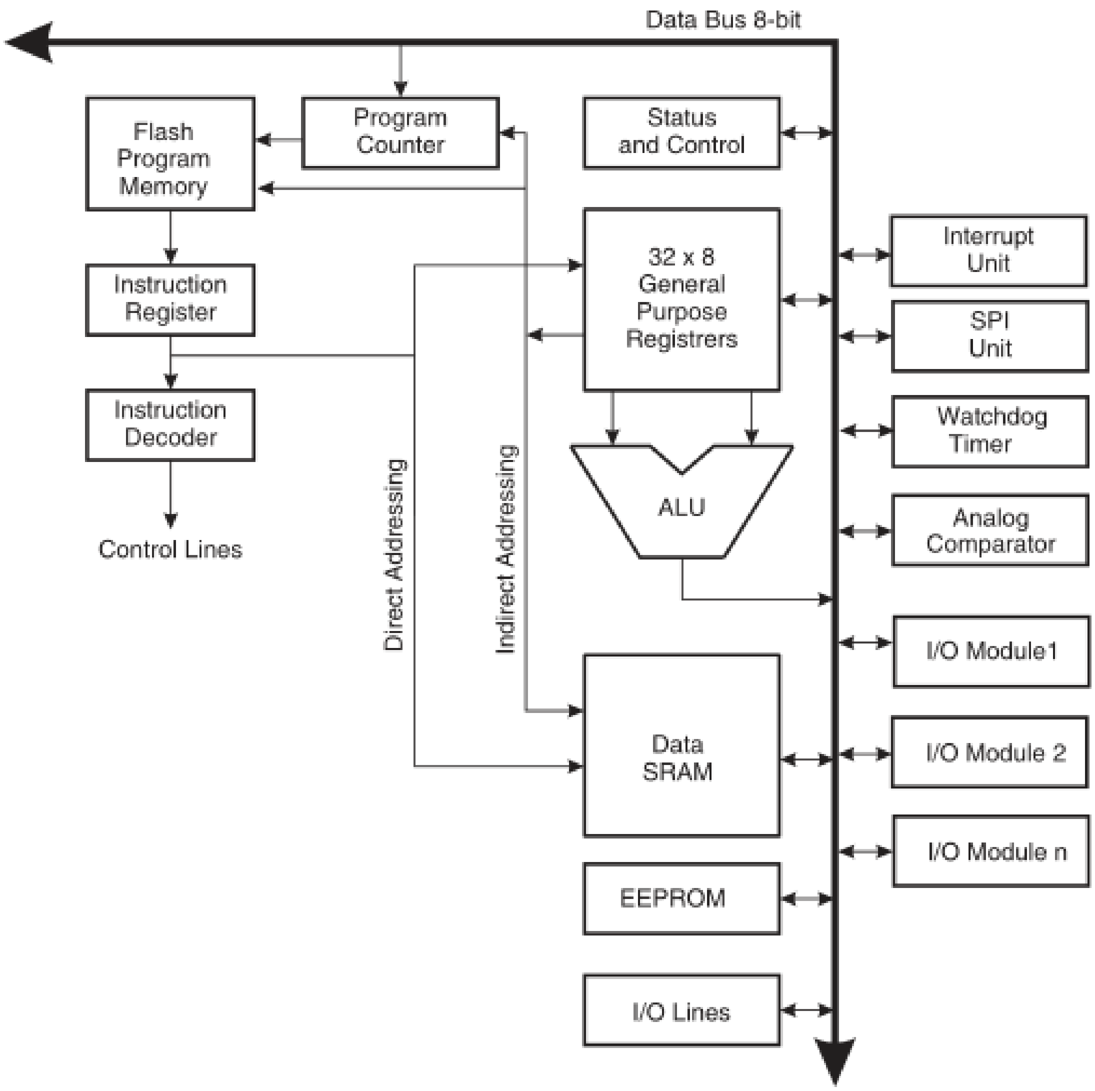

Figure 3.16: Microprocessor Block Diagram [7]. *Consent to reproduce figure requested.*

3.3.13 Camera

Another objective that the hydroponics system has is to be able to send updates to the user that include pictures of the plant that they are currently growing. It is hoped that a timelapse series of images can be displayed to the user to make a video display of the plant growing within the user application. In order to accomplish this task, a image sensor must be implemented into the design of the hydroponics system.

The main objectives that this subsystem needs to accomplish are:

- Take periodic digital pictures of the plant growing in the hydroponics system.
- Send digital photo information to on-board flash storage or to the Wi-Fi module to enable user access to the photos.
- Be able to withstand outdoor environments including harsh sun and rainy weather.

Table 3.25 shows the specifications which the camera subsystem must maintain.

Specification	Value
Measurement	640x480 pixel images
Storage	5 Minutes of video stored on device.
Lifespan	6 Months continuous Use

Table 3.25: Specifications for the Camera Subsystem

Table 3.26 below shows an itemized list of the parts to be used in developing the hydroponics prototype with this particular subsystem.

Part	Description	Cost
Omnivision OV07690-AL9A	A low power low cost CMOS image sensor	$15.00

Table 3.26: Parts for the Camera Subsystem

The design for the camera sub-system of the hydroponics system will involve a data bus for digital transmission of images into the microcontroller as well as a communication port into the camera for the settings of the camera. The Omnivision OV07690-AL9A CMOS camera will work fine for the prospective application required by the hydroponics project. This particular CMOS camera is a low power and low cost device that has added features including Automatic Exposure Control (AEC), automatic white balance (AWB), and automatic black level calibration (ABLC). The power requirements for the device is 2.6-3.0V and it has a power requirement of 100 mW. An additional up side to this model of image sensor is that it has a broad temperature range which is ideal for an outdoors application such as the hydroponics system and also is not made from lead which is harmful to the environment. The dimensions of the camera are 2512µm x 2967µm x 2465µm, which is very small.

The image sensor is mounted on its own small PCB design that comes with a 40 pin header for the wiring that connects to the microcontroller. The PCB design for this board should be relatively simple when compared to the microcontroller PCB. The camera can be mounted onto the pcb and then placed on the outside of the hydroponics unit. Also, it should be placed in a position that is able to clearly see the plants that are being grown throughout the growing period.

An important aspect for the design of the camera subsystem is outdoor operation of the camera. For outdoor operation, the camera must be located in a secure area on the hydroponics unit that is safe from precipitation. The data bus, power, and settings wires are also located through a watertight section of the hydroponics system for protection against perception. This can be done by simply building a rectangular shaped tunnel that goes from the microcontroller compartment to where the camera is located on the water tank. Another possible solution for keeping the camera and wiring away from precipitation could be to have the camera attached to the top of a rod that is placed on the hydroponics system. The rod could potentially move up and down like the antenna on an automobile using a small motor that is controlled with the microcontroller.

3.4 Software Design

The software design plays a very important role in this project. A large portion of the project's functionality is implemented through the software. For this reason, activity and state diagrams are included in the following sections for a detailed analysis of the flow of the system, server, and end application.

3.4.1 System Design

After consideration of different microprocessor coding environments, a group decision was made on the Arduino IDE environment. This environment is the best choice for this project because its features outweigh TI's Code Composer Studio environment. Communication and setup of the Wi-Fi module will occur in a serial monitor and Arduino's built in monitor facilitates then need with an ease of use and no need for any external applications. Also, the Arduino IDE offers extensive open source libraries that are applicable for use in this project. Another decision factor was that Arduino's high-level object-oriented coding language is easier to code in than C or Assembly languages. The Arduino IDE also doesn't limit the code space and is completely open source and free to use.

Activity Diagram - To help describe how the processor's software will execute, Figure 3.17 shows the activity diagram for the system.

The system starts when a user initially "flicks the switch" and turns the system on. The system will then enter an initial setup phase where a few steps happen. First, power is

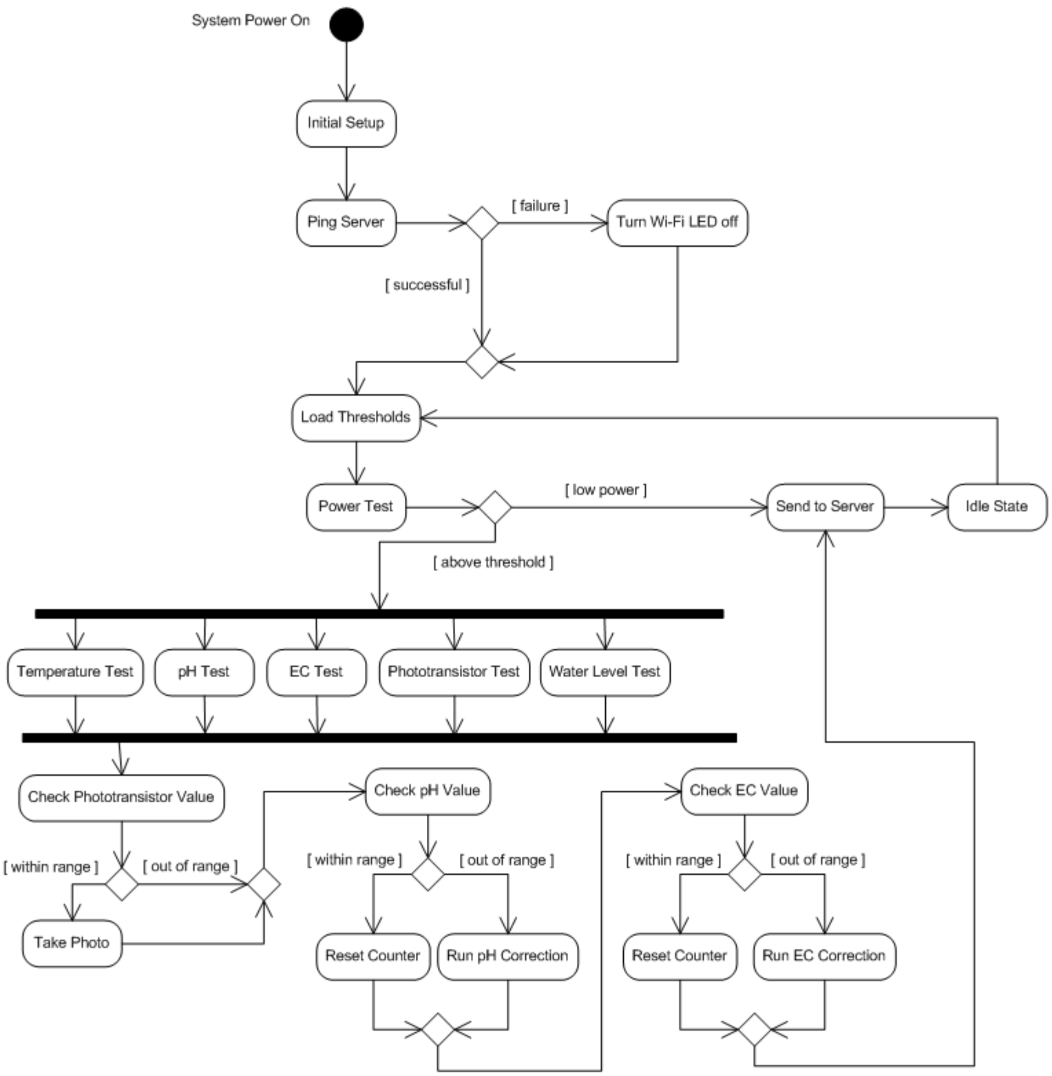

Figure 3.17: System Activity Diagram

sent to the air pump to start it running. At the same time, power is also sent to the power and status LEDs. The power LED indicated that the system has power while the status LED indicates the status of the pH and nutrient adjustment liquid tanks. The status LED will always be activated when the system is first turned on but will change after subsequent testing reveals that the nutrient and/or pH levels are not being adjusted. Next, the system will test the Electrical Conductivity (EC) of the base water being used with no nutrients. It will store this value and add it as an offset to the EC thresholds used in EC tests. This step accounts for the conductance of the water used and will ensure accurate readings of the EC after nutrients are added. In the next activity, the system will configure the Wi-Fi settings needed to join a pre-specified network and connect to a web server. Settings include SSID, passphrase, and security type (WEP, WPA, WPA2, etc.) along with the server IP address and port number. After this setup, the system will ping the server to verify a positive TCP connection. If the ping was successful, the

Wi-Fi LED will receive power and turn on. These steps will occur when the system is first turned on and will only execute once.

The next step is to load the threshold values for the system. These threshold values include pH range, EC range, and phototransistor range (sunrise to sunset). These values will be stored in variables and are subject to change by user input via the website. User's specified plants will have corresponding pH and EC values that will be transmitted to the system and stored in these declared variables. If the user does not specify any values, default youth plant values of pH = 6.0-6.5 and EC = 0.8-1.2 will be used [25]. Each time the system performs this activity any changed values will be updated. Next is a power test. If the power is below a defined threshold, the system will send a low power message to the server. The system will then loop and enter an idle state for 25 minutes. During this state, the system will use very little power. After this timeout, the system will return to the load threshold activity. After this activity, it will run the power test again until the power is above the threshold value. During this "low power loop", no sensor testing will be performed and no sensor data will be sent to the server to conserve battery life. The only component that will be running is the air pump. Once the battery has sufficient charge above the threshold value, the system will exit the loop and continue to the next activity which is sensor testing.

Each sensor will be polled for values. A sensor test will be performed for temperature, pH, EC, photoconductivity (phototransistor), and water level. After each test the sensor values are translated into usable values. This is needed because the values obtained from the sensors are not the values used in the threshold calculations. For example, the pH sensor returns millivolt values that need to be translated into pH values on the pH scale of 0-14. This translation can be achieved by calibrating the sensors beforehand. For example, taking the reading of the pH sensor in two different liquids of known pH will create a linear relationship between the two. The derived equation can then be used in the translation calculation.

After all sensor translation, the phototransistor value is checked to see if it is within the threshold values. If it is, the camera will take a picture and store the data. Then, the pH value will be checked to see if it is within the threshold values. If it is not, the pH correction activity will run. The pH correction will activate the peristaltic pumps that add pH down or nutrient liquid. If the pH is too high, the pH down peristaltic pump will activate and disburse pH down liquid into the reservoir. If the pH is too low (event doesn't occur often), the nutrient peristaltic pump will disburse the nutrient into the reservoir. More nutrients added to the reservoir act as a pH up and enables the project to contain one less pump. The amount of liquid the peristaltic pumps disburse will be calibrated beforehand. This will give an accurate measure of the relationship between the time each pump is on and the amount of pH adjustment. At the end of the pH correction activity, a counter is incremented. This counter is used to count the number of times the pH correction activity runs on consecutive sensor tests. For each pH test that is within the threshold values, the counter is reset to 0. If the counter reaches four, an assumption is made that the system is out of pH down or nutrient liquids and the status LED is turned off. When this occurs, the pH test value is changed to 0. A value of 0 sent to the server triggers an email and/or text message alerting the user. Upon completion of the pH threshold check, the EC threshold check follows the same steps. If the EC is below the minimum threshold, the peristaltic nutrient pump disburses more nutrients. No correction is done for an EC measurement above the maximum threshold value. This event will not happen unless the user adds external nutrients to the system. With time, the EC will decrease as the plants absorb more nutrients. A different counter will be used for EC tests and be adjusted in the same format at the pH tests except that an EC measurement above the maximum threshold value with not increase the counter.

After both pH an EC threshold tests, all sensor values and photo (if taken) are sent to the server (if a connection can be made) using the Wi-Fi module. If a connection cannot be made, the stored values will be rewritten on the next subsequent test. After this event, the system loops and enters the idle state for another 25 minutes. After this timeout, the system will load any new threshold values and move into another power test and start the process again.

State Diagram - The main purpose of the system is to run sensor tests and send the data to the web server. Figure 3.18 describes the process of how this happens by showing the different system states and how they relate.

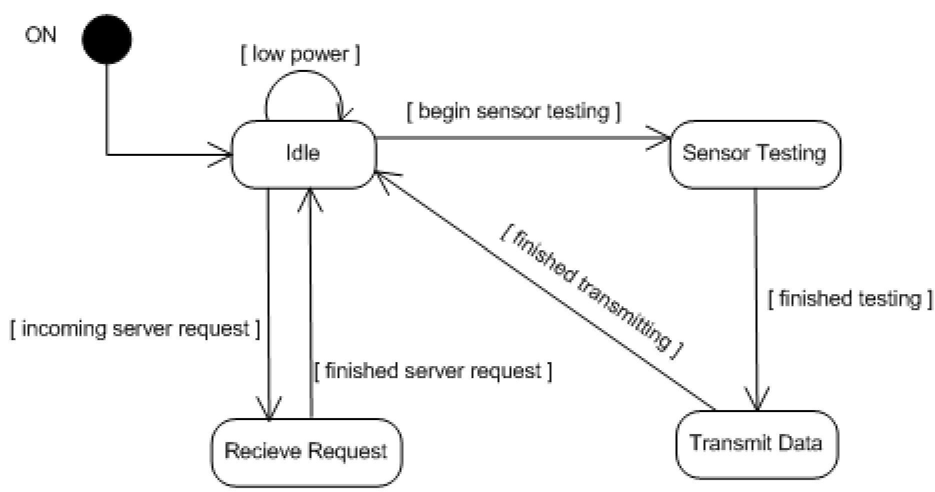

Figure 3.18: System State Diagram

After the system turns on and completes its initial setup, it enters the idle state. In this state the system is using little power and is waiting for the next sensor test or for a request from the web server. The web server would be sending threshold values specified by user input on the website. If the server sends values, they are stored in the system and updated before the next sensor test. If the system is low on power, it will stay in the idle state and check the power level at the end of each timeout. Once the system begins sensor testing, it enters the testing state where it completes all tests and corrections. In then moves into the transmit state where the data is transmitted to the web server. After transmission, the system returns to the idle state.

3.4.2 Web Server

After consideration of different web servers, Node.js was chosen for this project for a few reasons. Node.js has a smaller learning curve compared to using Apache HTTP server. Node.js can create a web server, dynamic webpages, and database access all in JavaScript. Using Apache requires an understanding of PHP and a database language like SQL and may not be achievable to learn and implement this in the project time frame. Also, group members have previous experience with creating web applications using Node.js. Along with fast access time, Node.js is a perfect choice for real-time applications because of its non-blocking asynchronous design. This enables the project to be scalable for many users in the future with little or no change to the server design.

Activity Diagram (Incoming Request) - To understand how the server will interact with the system, Figure 3.19 below describes the different activities the server will perform when a HTTP post request is received from the system.

The first step is receiving of the request from the system and extracting the data in variables. The request IP address along with a timestamp will be added to the set of data. The timestamp and IP address will be used for different server processes described in the latter sections below. The system will send two different post requests: one with sensor values and one for low power. If the request is a low power request, the server will notify the user via email/text message that the system is running on low power. Sent with each post request is a unique device ID number that the server will use to lookup the corresponding user with that device ID. The server will then store the low power data along with the device IP address and a current timestamp in the database for use when the server is idle (see idle section below) The low power post request connection is then terminated by the server.

If the incoming post request contains sensor data, a different activity flow will occur. Once the data is extracted, it is stored in the database. Next, a comparison is performed on the timestamp of the incoming request and the oldest timestamp that the database has stored (first day of system testing). If the incoming timestamp is greater than 45 days, three steps are taken. One, using the device ID sent in the request, the user is notified that the EC levels will be increased. Two, the server checks the user to see if they have entered any information on the website (when registering) about the type of plants they are growing. If the user enters their plant type, the database will have stored EC values for the plant during youth and adult stages of growth. After 45 days, the plant will be considered an adult and the adult EC values will be sent to the system using the IP address stored from the incoming request. If the user did not specify a plant type, default EC values of 1.2-1.8 will be sent to the system. The third and final step is that the system stores the incoming timestamp as the oldest (first received) timestamp. This is to ensure that this EC change activity will not occur again with future incoming

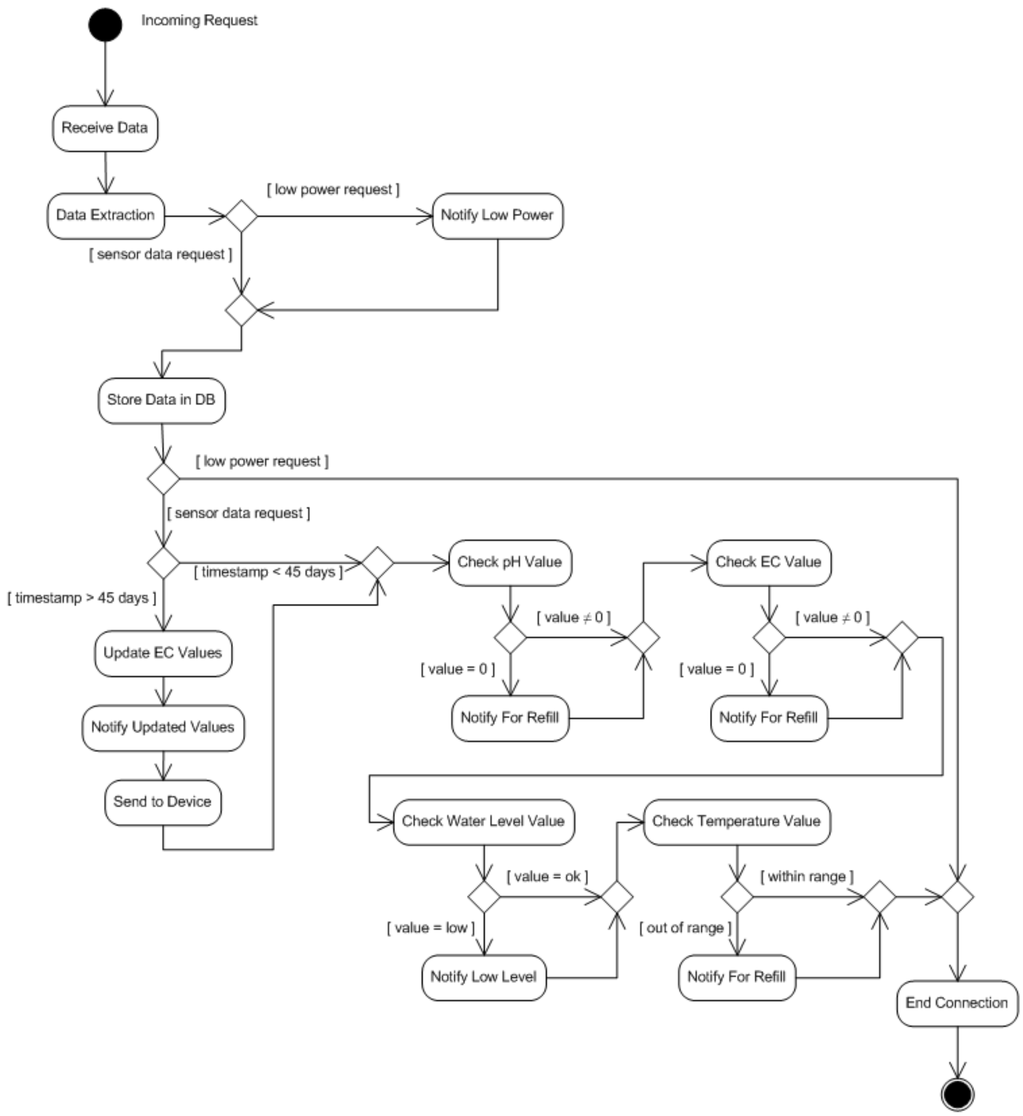

Figure 3.19: Server Activity Diagram (Incoming Request)

requests from the system.

After this step, or if the time stamp is within 45 days, the server one by one checks each sensor values to see if they are within the threshold range. The server checks the pH, EC, water level, and temperature and notifies the user of potential problems or action required. If a value of 0 is received for the pH or EC sensor value, a notification is sent to the user alerting them that the pH or nutrient liquid tanks need refilled. Once all values are checked and notifications sent, the server terminates the TCP connection with the system.

Activity Diagram (Idle) - The server will handle incoming post requests from the system and events triggered by user interaction with the website. The period when the server is not receiving post requests from the system in classified as the idle period.

Figure 3.20 below summarizes the server activities during this period.

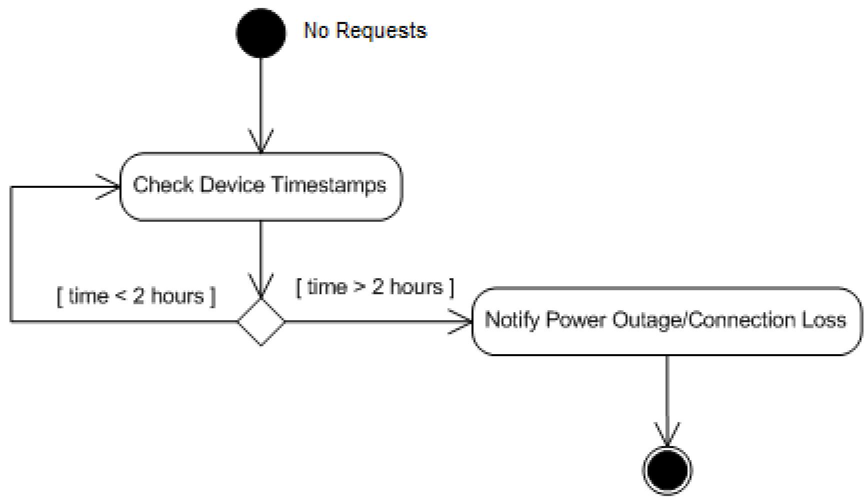

Figure 3.20: Server Activity Diagram (Idle)

During this period, the server will continuously loop through each device ID and compare the current time stamp to the time stamp of the most recent post request received from a system. If this time stamp is greater than 2 hours, it implies that one of two things: the system has lost power, or the system has lost connection to the network. When this occurs, the user is sent a notification email or text message alerting them to the situation.

Notifications - Periodically, messages will be sent to the user to indicate different states that the hydroponics device is currently in. Table 3.27 summarizes the different notification messages that will be sent by the server to the user via email or text message.

Type	Message
Low Power Level	System is running on low power. No sensors will be tested until batteries recharge. Consider moving solar panel to a location with more sunlight.
EC Change	Your plants have reached an adult stage of growth and will be receiving a high concentration of nutrients. Nutrient and pH down refills might occur more frequency than before.
Refill Nutrient Liquid	The sensors indicate that the nutrient level is not being adjusted properly. Please check the pH down and nutrient tanks and refill if necessary. Please also check your water filter for residue build up and rinse if necessary.
Refill pH Liquid	The sensors indicate that the pH level is not being adjusted properly. Please check the pH down and nutrient tanks and refill if necessary. Please also check your water filter for residue build up and rinse if necessary.
Low Water Level	The sensors indicate that the water level is currently low. Please check the hose or water supply attached to the system for adequate flow.
High Water Temperature	The sensors indicate a water temperature above $27\,^{\circ}$C. This raises the potential for harmful bacteria growth in the reservoir. Consider moving the reservoir into a location that is partially shaded for a portion of the day. Another option is to add beneficial bacteria to the solution that can protect the roots from harmful bacteria and root rot. A sample product for this purpose would be AquaShield [4].
Low Water Temperature	The sensors indicate a water temperature below $15\,^{\circ}$C. Please consider moving the reservoir into a sunnier location or indoors if necessary.
Power Outage or No Network Connection	The server has lost connection the system. This could indicate a power outage and/or loss of connection to the network. Please verify the system Wi-Fi network is active and consider plugging the system into AC power from an outlet.

Table 3.27: Summary of Notifications to be Sent to the User

State Diagram - The server's primary tasks are to handle requests from the system and a user. Figure 3.21 below shows the state diagram of the server and the connections between states.

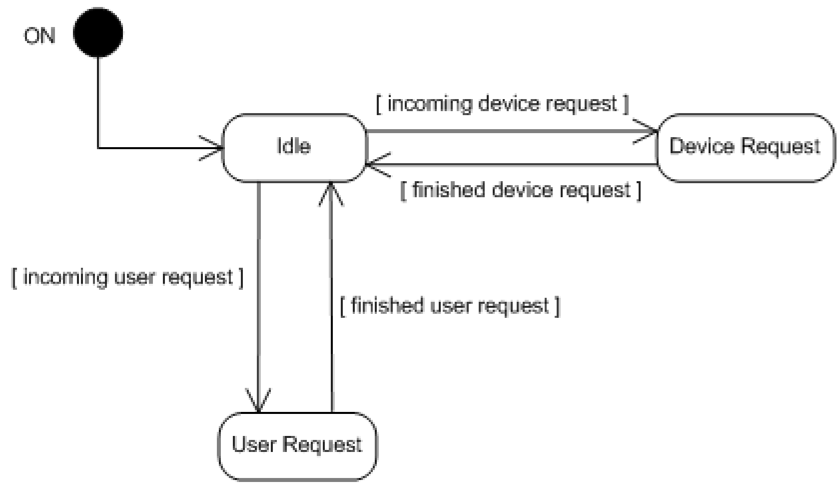

Figure 3.21: Server State Diagram

The server has three main states. When it is not handling requests from the user or system, it is in an idle state checking the each device time stamp and notifying the user of a power outage/lost of connection as described above. As a system request is received, the server handles the request, storing the data in the database and notifying the user if necessary. As a user request is received, the server handles the request, performing tasks like logging the user in, displaying data, or logging the user out. After each request is handled, the server returns to the idle state.

3.4.3 User Application

The application design focuses on the front end experience and interaction of the user with the product. The user will interact with the product through a website interface built using Node.js. The project is based on the client-server model where each user will send requests that will be handled by the server. The user will have various options to set up an account and view sensor data from the system.

Activity Diagram - Figure 3.22 shows an activity diagram of the application and the functions and features available to the user through the website interface.

When the user first accesses the website, they will be directed to a welcome page. This page will have an overview of the product and links to login or register. If the user is not registered, they will be redirected to a registration page. On this page the user will enter information such as name, email, password, phone number, phone carrier, and the device ID of their system. The device ID will be used by the server to accurately notify the correct user of situations occurring with their specific system. Once this

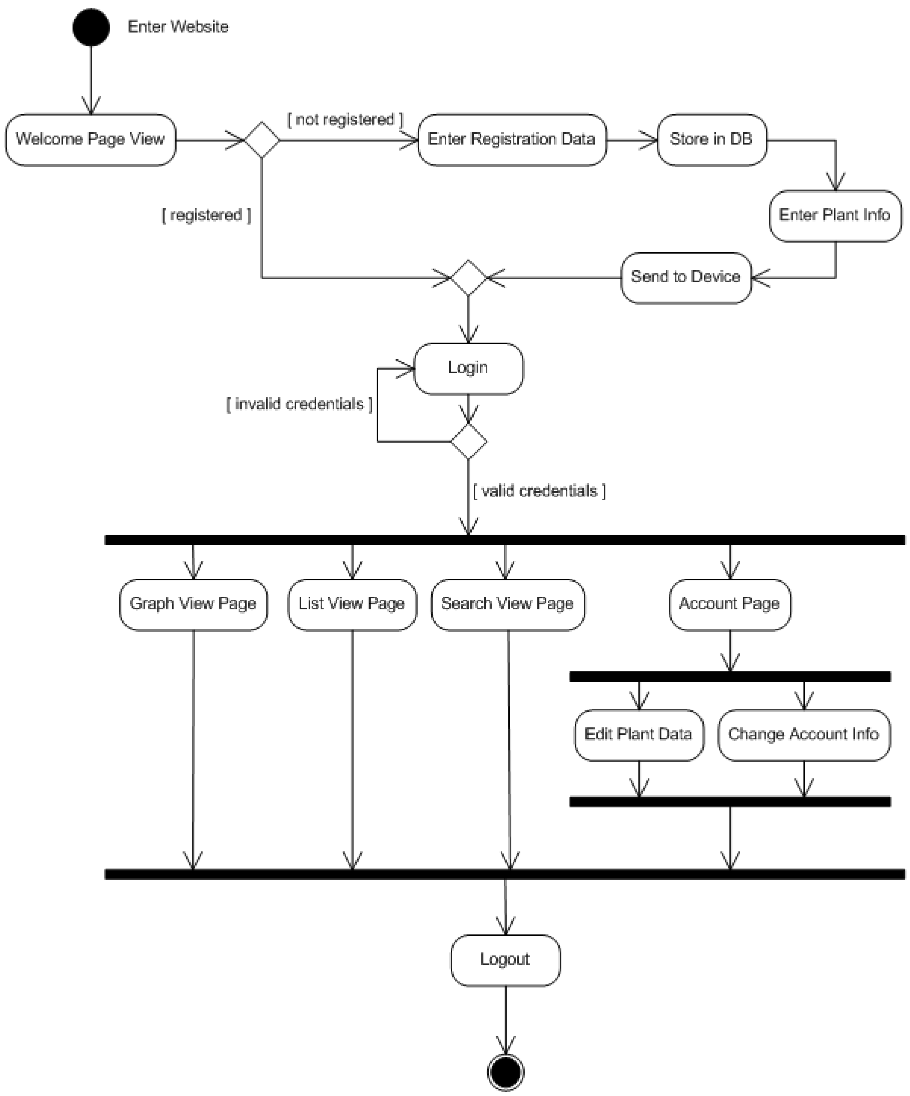

Figure 3.22: Application Activity Diagram

information has been entered, it is stored in the database as a new user. The new user is then directed to a plant page where they can specify which plants they will be growing using the system. The user is not required to enter this information and can skip this step if desired. If entered, the plant specific information will have corresponding pH and EC values that have been predetermined and stored in the database. These values will then be sent to the system to re-calibrate it to the plant specific settings. If no plant is specified, default system values will be used. Upon completion of this step, the user will be redirected to the login page.

Once registered, all users will need to login. Each user will login with their email and password and the data will be verified in the database. If the user does not enter valid credentials, they will be redirected to the same login page to try again. After a successful login, the user is brought to a home page with a product overview and the option to navigate to different pages. The website will have a menu or buttons that will link to different pages. Table 3.28 describes the different pages accessible by the user.

Page	Description
Graph View	Plots sensor data for each sensor on a graph to view history. Values will be on one axis and time on the other. Graph view will also have a stop motion capture video of plant growth photos taken from the camera (time permitting).
List View	Table format in chronological order starting with the most recent data entry from the system. Each sensor value and photo (if taken) will be in a respective column.
Search View	User can specify a sensor field to search from a drop down list and also an optional condition (eg. pH > 6). If no condition is specified, all results for the field will be returned. Results will be displayed in a table format with a time stamp and search field in respective columns.
Account	Option to change account information such as name, email, phone number, or password. User will also be able to add or modify the plant type stored in the database for their system.

Table 3.28: Summary of Web Pages Accessible by the User

Once the user has finished activity on the website, there will be a logout button (accessible from all pages after a user has logged in) which will log the user out and end the activity flow.

3.4.4 Database

After consideration of different database designs, it was concluded that a non-relational database would be more beneficial than a relational database. For this project, a MongoDB database was chosen for a few reasons. First, group members have used MongoDB in previous projects and are familiar with the API, which allows for a quick implementation. Also, MongoDB's fast access and high-level object-oriented API facilitate an ease of use and a small learning curve. Finally, MongoDB is compatible with Node.js and can be accessed using JavaScript through helper modules.

For organization and a conceptual understanding of connections, the database is broken into tables. Figure 3.23 below describes the schemas and the connections between them. In reality, MongoDB stores the data in documents and not in table format. The tables below are a visual representation of the information stored in each document and the relationship between them.

The database will store a document for each user. The document will include an email, password, name, and phone number. A device ID will also be included as the specific device ID for that user's system. This device ID will be used to find all sensor data entries that have the same device ID. An optional plant name field is included that

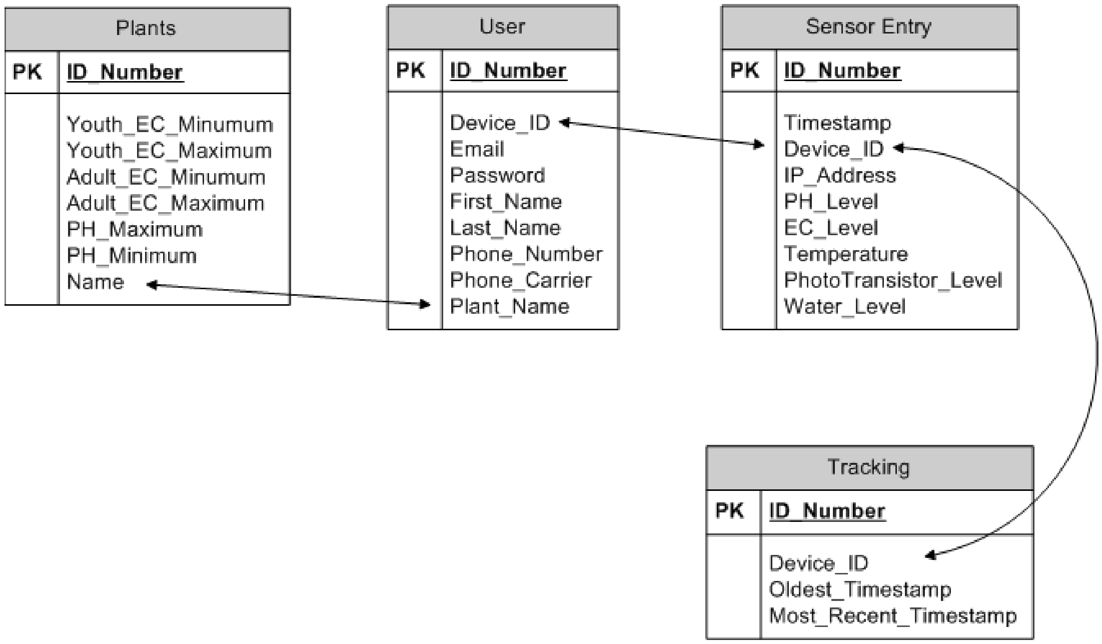

Figure 3.23: Database Tables Diagram

specifies the plant type the user is growing. This plant name will reference a plant document. When values need to be extracted from a user's plant type, the information will ultimately be extracted from the plant document.

The plant documents will store information about various hydroponic plants. Each document will include EC values for youth and adult stages of growth along with pH values that remain constant throughout growth. EC and pH values each have an upper and lower bound.

A document will be created for each sensor entry incoming from the system. Each sensor value will be stored in the document along with a time stamp, device ID, and IP address of the system. The IP address is stored and used to send data back to the system. The device ID links to a specific user and to a tracking document.

A tracking document is created for each device ID and is used to keep track of the time sensor data is received. An oldest time stamp is stored and represents the first sensor data received from the system. A most recent time stamp is stored to keep track of when the most recent testing was done. This is used in determining if the system has lost power or network connection. The server compares this value with the current date and time and notifies the user if sensor data has not been received for a prolonged period of time.

3.4.5 Requirements

In conjunction with the Arduino IDE environment and Node.js platform, external libraries will be used for each to extend functionality and provide APIs for use. Table 3.29 below lists the libraries that will be used for each and their function [3]. All libraries and APIs used are open source.

Library	**Function**	**Source**
EEPROM	Read and write to "permanent" storage	Arduino IDE
SPI	Communicate to devices using the Serial Peripheral Interface Bus	Arduino IDE
Wi-Fi	Connect to internet over Wi-Fi	Arduino IDE
SoftwareSerial	Serial communication on serial pins	Arduino IDE
MSTimer2	Using the timer 2 interrupt to trigger actions every N milliseconds	Arduino IDE
nodeMailer	Send emails	Node.js
mongoose	Wrapper to connect and use MongoDB	Node.js
dc1.0.0	Create graphs and charts	Node.js
passport	User login and logout authentication	Node.js

Table 3.29: Arduino IDE and Node.js External Libraries to be Used

3.5 Design Summary

The following figures summarize the design of the hydroponics system. This section includes block diagrams, dimensional drawings of parts to be used, as well as a drawing showing where the item will be placed.

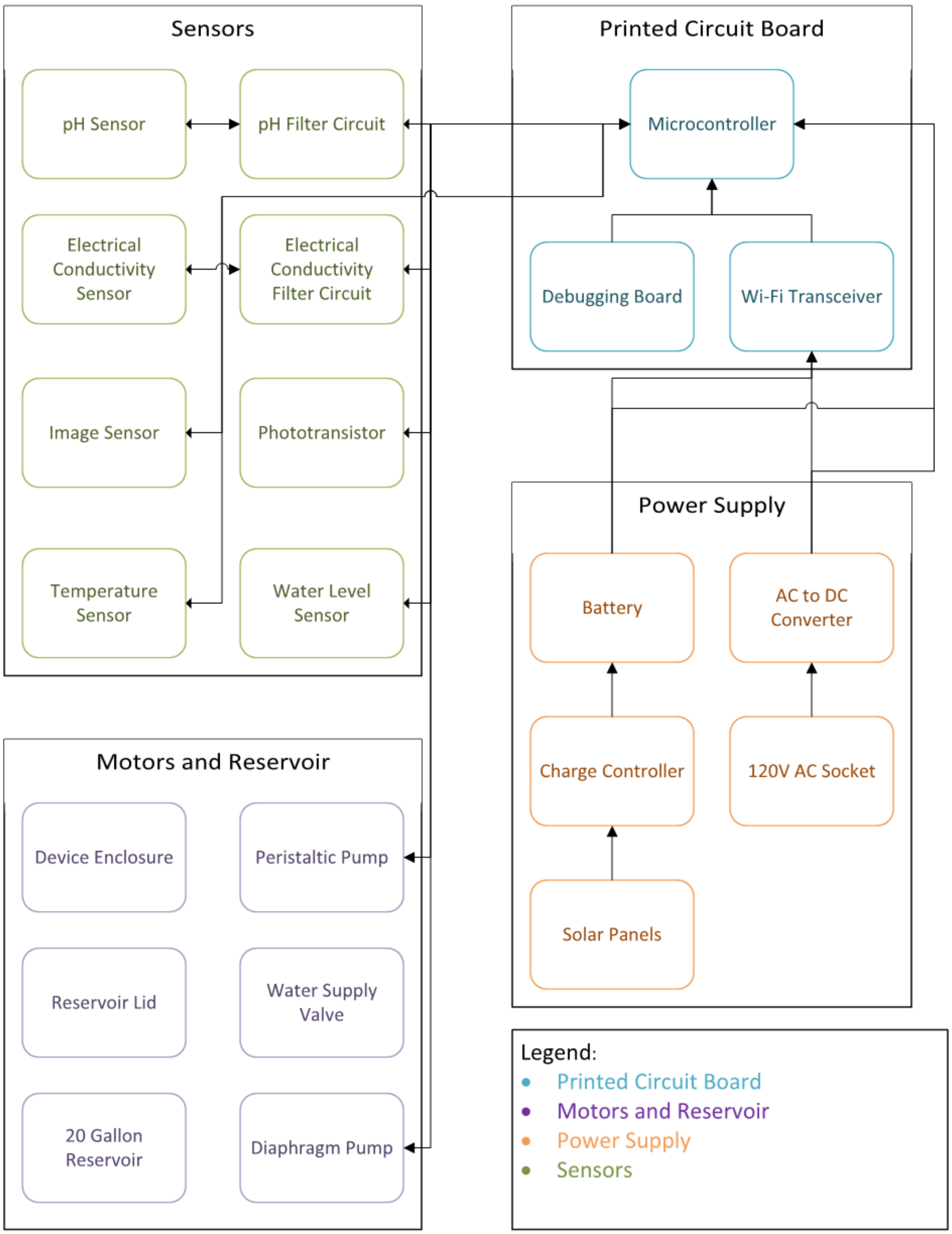

Figure 3.24: Hardware Block Diagram

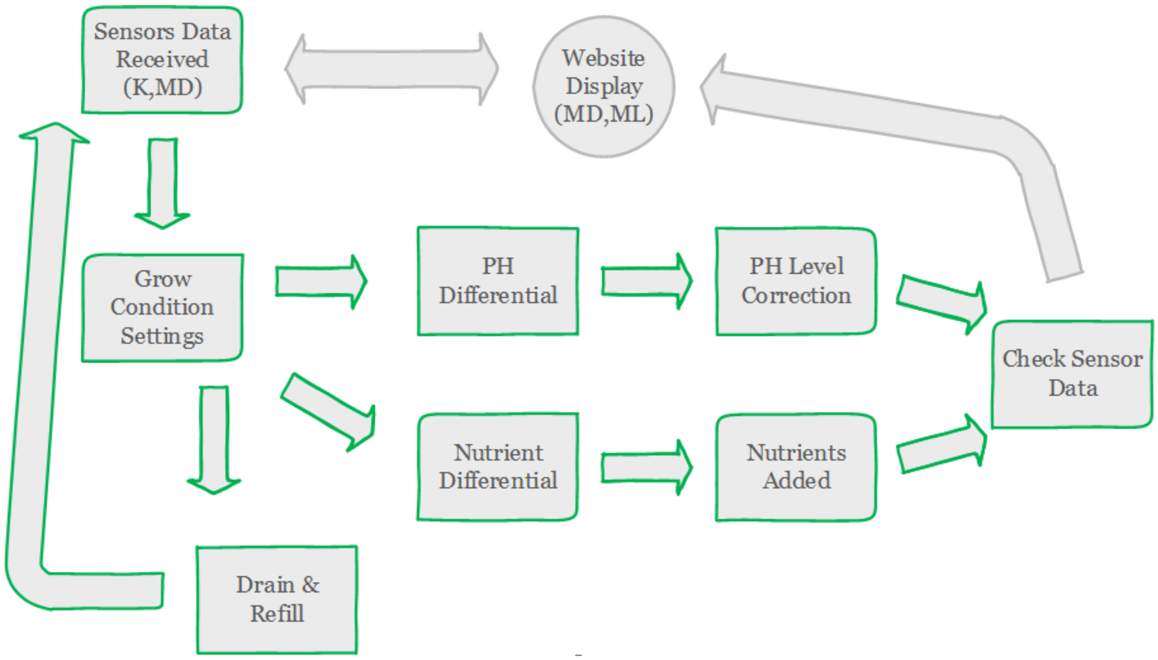

Figure 3.25: Software Block Diagram

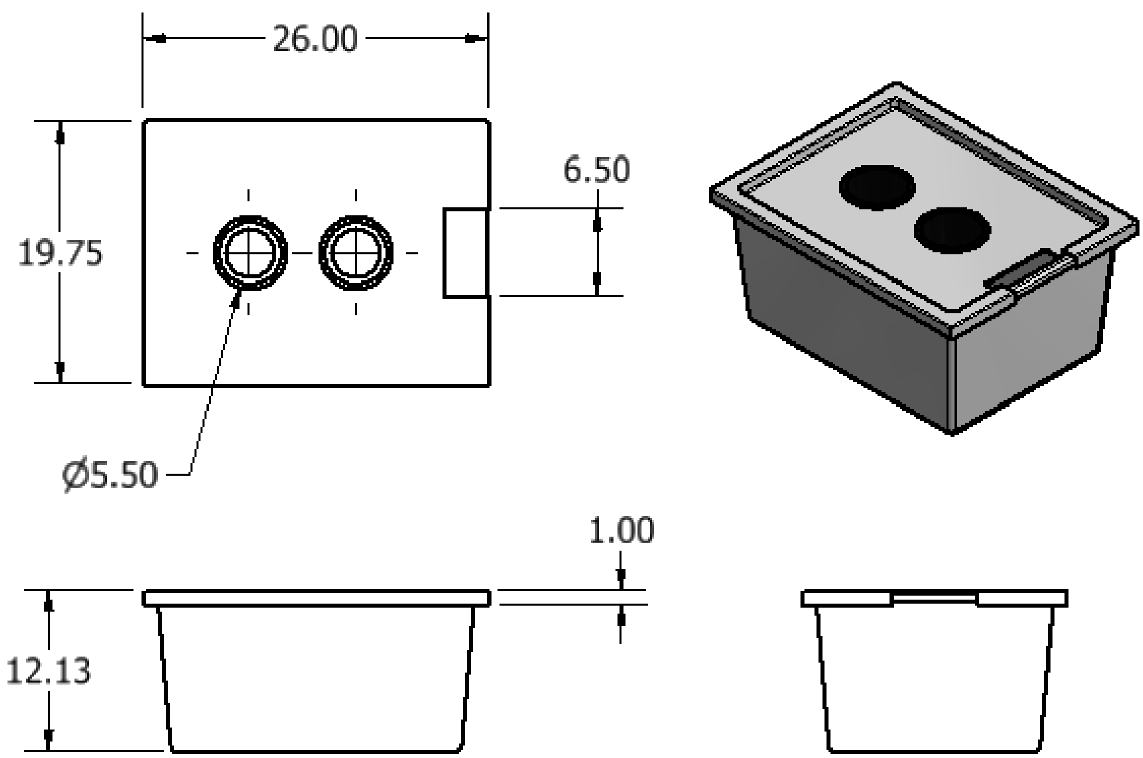

Figure 3.26: Dimensions of the Hydroponics Reservoir. (Inches)

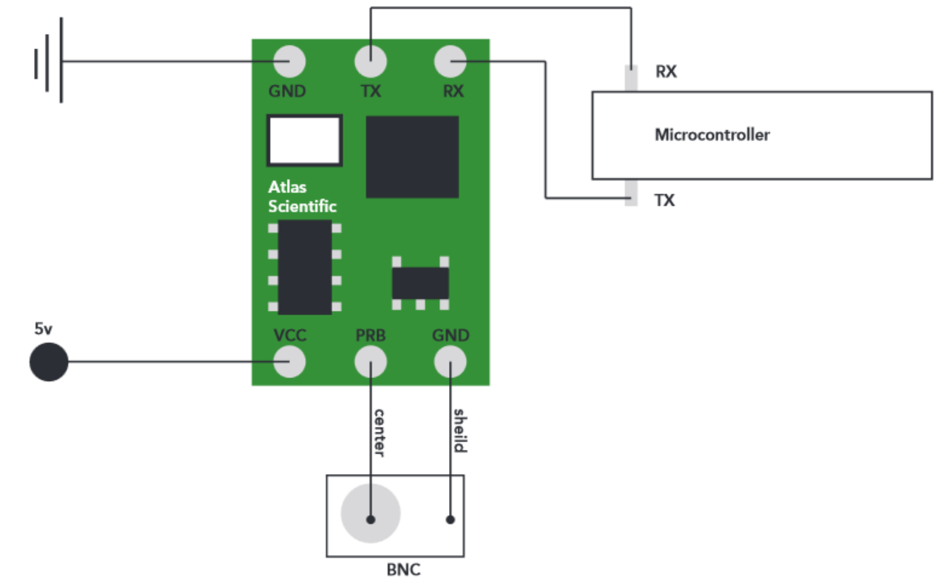

Figure 3.27: Schematic Diagram of the Atlas Scientific EC Meter

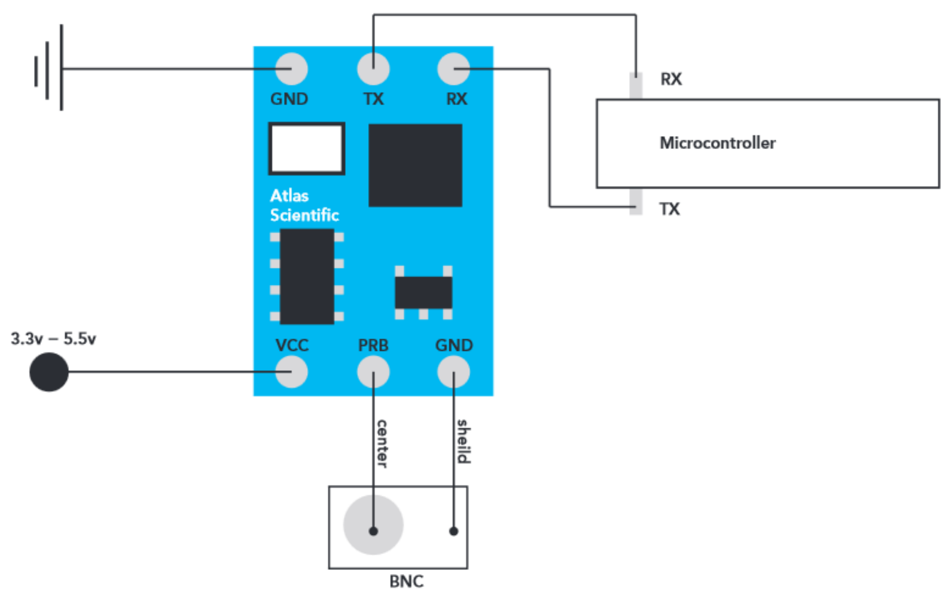

Figure 3.28: Schematic Diagram of the Atlas Scientific pH Meter

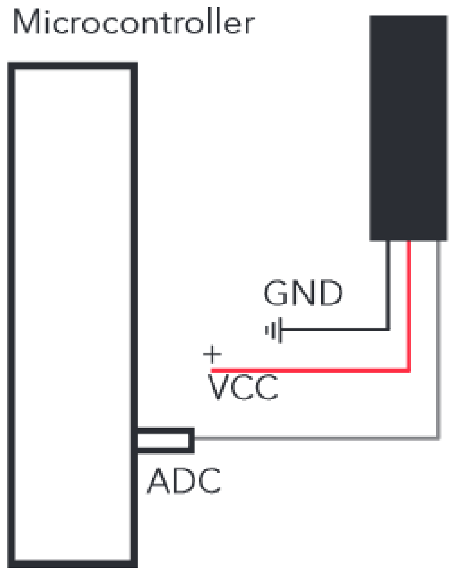

Figure 3.29: Schematic Diagram of the Atlas Scientific Temperature Meter

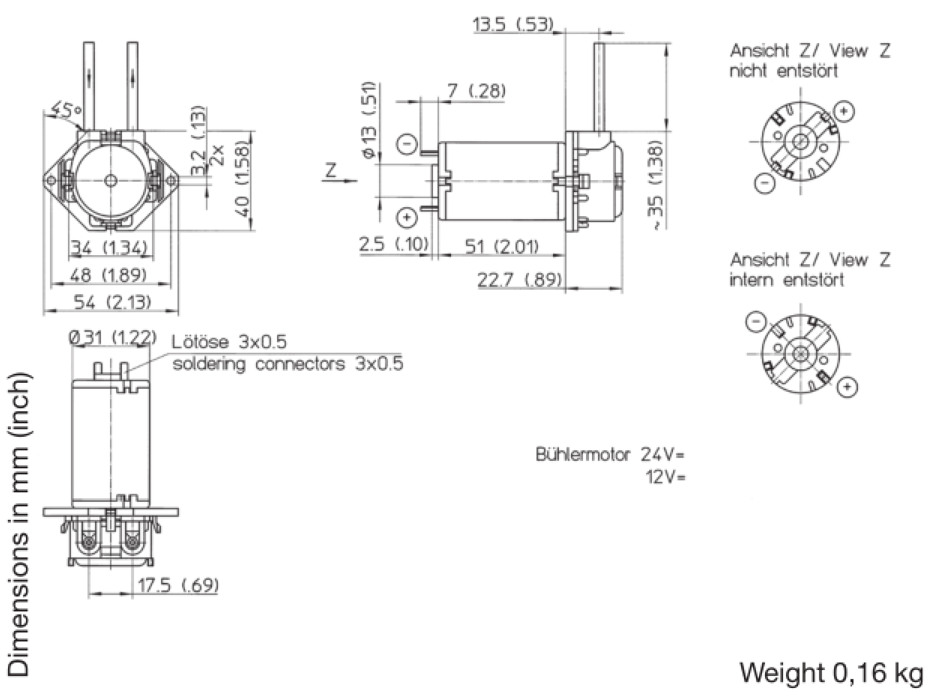

Figure 3.30: Multiview Schematic Drawing of SR10/30 DC Straight Flange Pump

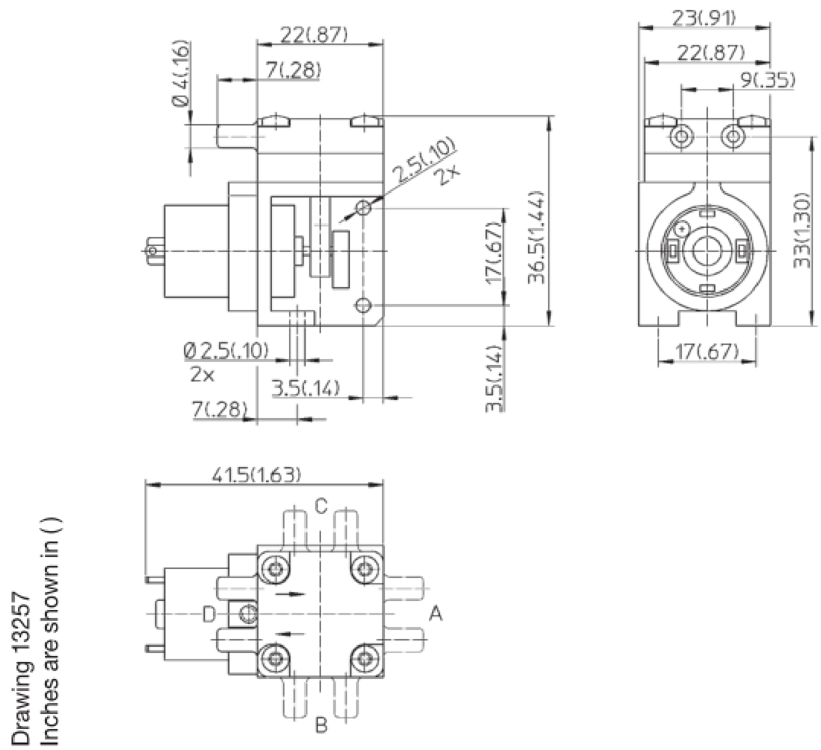

Figure 3.31: Multiview Schematic Drawing of 3003VDLC Diaphragm Pump

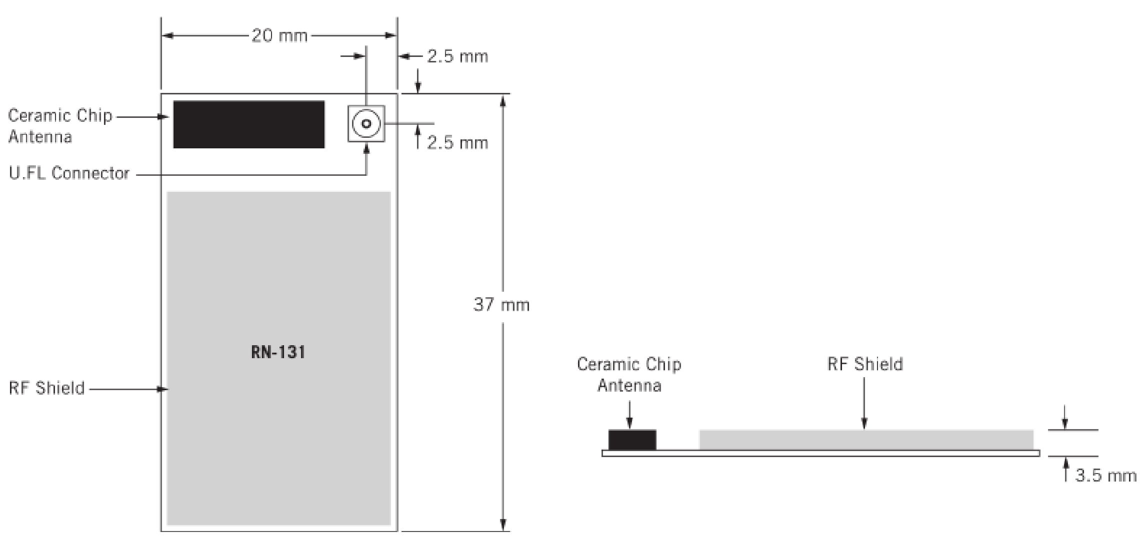

Figure 3.32: A Multiview Schematic Drawing of the RN131G Wi-Fi Transceiver

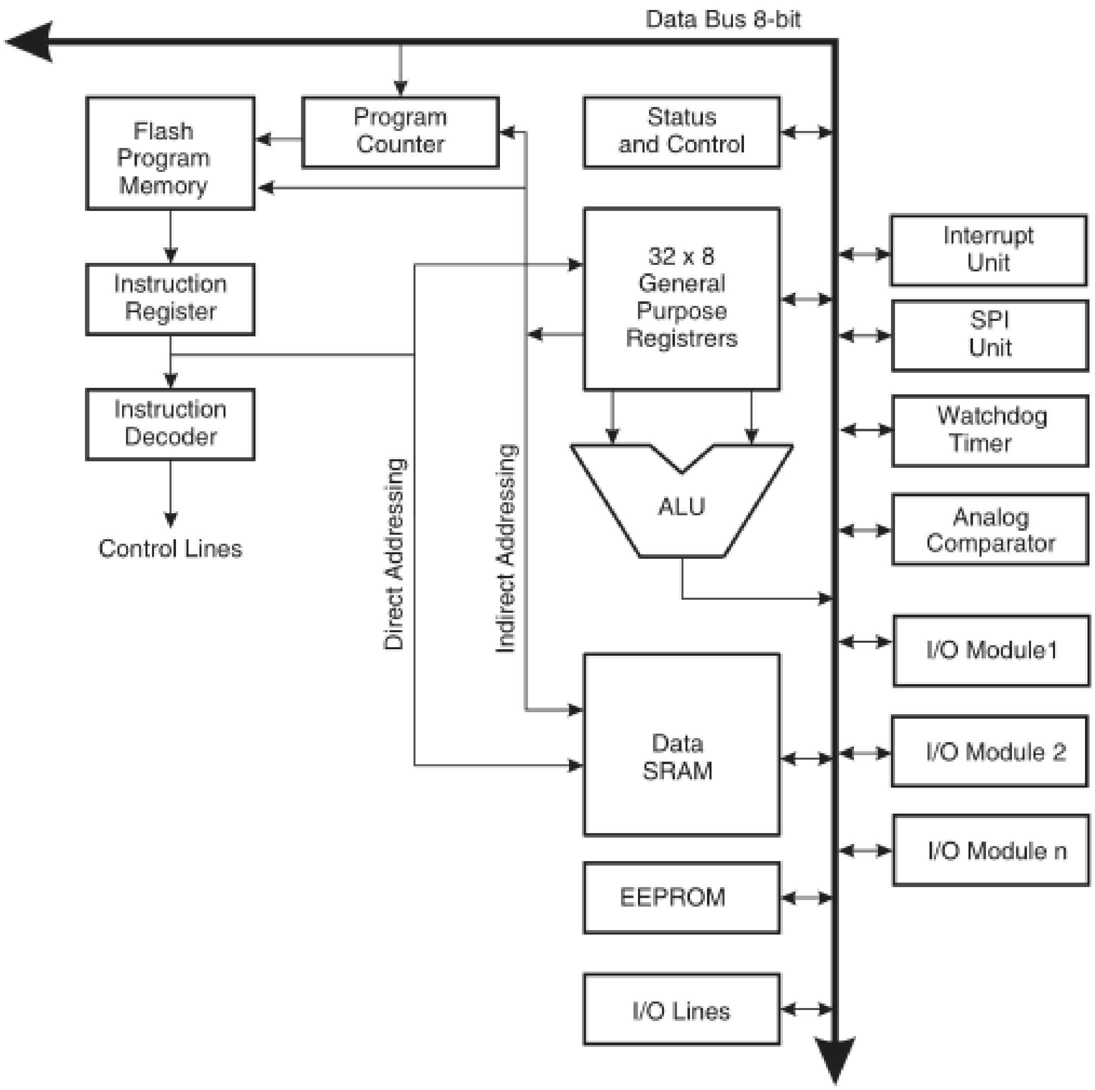

Figure 3.33: Microprocessor Block Diagram

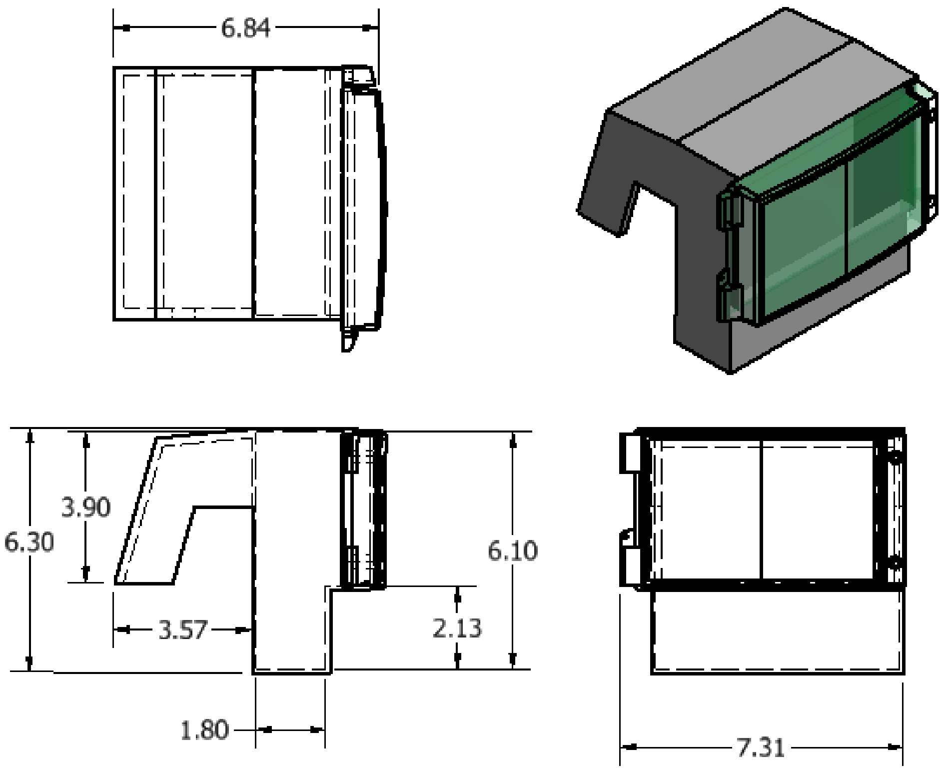

Figure 3.34: Modified Enclosure Multiview. (Inches)

PARTS LIST		
ITEM	QTY	PART NUMBER
1	2	SR1030 Pump
2	1	PCB
3	1	3003VDLC Diaphragm Pump
4	1	Fibox PC 17-16-L3
5	1	EZO circuit
6	1	pH circuit
7	1	pH Probe
8	1	EC Probe

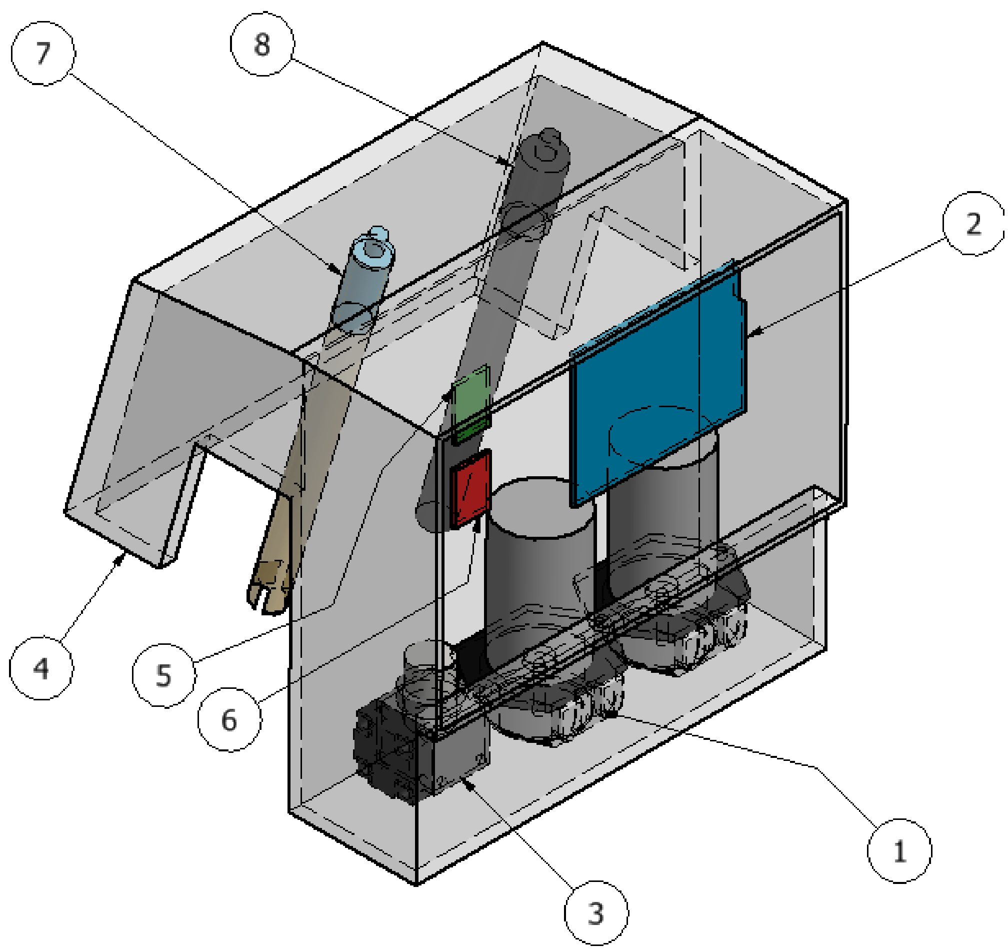

Figure 3.35: A Parts Diagram Showing Placement of Various Subsystems within the Enclosure

PARTS LIST		
ITEM	QTY	PART NUMBER
1	1	Plant Reservoir and Lid
2	1	Device
3	1	Temperature Probe
4	1	FloraDuoA
5	1	FloraDuoB
6	1	Battery

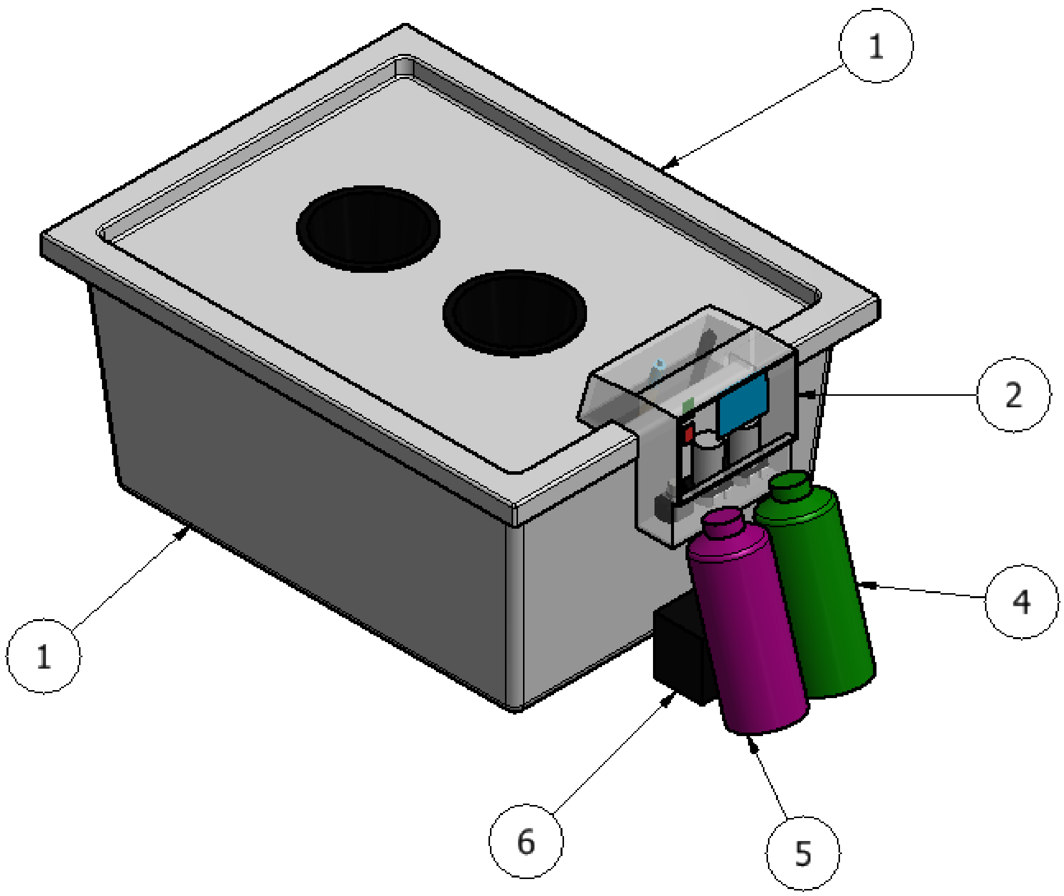

Figure 3.36: Overall Placement of Parts in Hydroponics System

Chapter 4

Prototype Construction

With the initial design of the hydroponics system complete, the next stage of the product development is to begin focusing on how design will be fully realized in the form of an initial prototype. The most important parts of this step are to scope out precisely how many parts there will be, and where the parts will be ordered or purchased from. This includes all of the hardware subsystems and main printed circuit board, as well as considerations on how the software will be written and implemented into the device.

The prototype construction chapter includes:

1. The plan for ordering a prototype printed circuit board and mounting components to the board.
2. How parts will be acquired, including distributors and stores where components are purchased.
3. A plan for how the software will be written, including the microcontroller and web server programming.

4.1 PCB Design and Vendor

For PCB manufacturing, there are certain things that need to be taken into consideration. First, a circuit needs to be designed in a specialized printed circuit board layout software. The first subsection will discuss different layout software that is available for use by the senior design team. The next subsection contains a discussion about the different printed circuit board manufacturing companies, and the advantages and disadvantages of each are also discussed. Finally, the electrical components that are part of the designed circuit need to be incorporated onto the printed circuit board.

If Eagle is deemed undesirable due to cost of licensing, a free alternative is Express PCB, which is easy to use and therefore good for beginners to use.

4.1.1 PCB Design Software

There are many different software packages available to design printed circuit boards with, and many printed circuit board vendors offer there own free software to entice customers to use their service. One of the premier software packages available right now for use is known as Cadsoft Eagle. The reason that eagle is such a strong choice and an industry standard is because it offers a full suite of options, as well as direct connections to the companies electrical component database. This allows the designer to easily choose components which are in stock and available for order, as well as generating a bill of materials automatically. One disadvantage to using the Eagle software is that the free trial is very limiting to what can actually be designed, and the other licenses are quite expensive.

4.1.2 PCB Vendors

In order to complete this project, an embedded system onto a printed circuit board must be designed and incorporated into the system. Usually, because the process of manufacturing complicated printed circuits onto substrate materials is very difficult, a design is created and then sent to a professional PCB manufacturing company. There are a multitude of PCB vendors to choose from for the manufacturing of this projects printed circuit board. The main criteria for choosing a vendor to send the PCB design created for this project are cost and time until delivery.

One of the main constraints of the hydroponics prototype is the financial budget, and so every device that is implemented into the project must be absolutely necessary and be as inexpensive as possible. Many different PCB vendors must be considered in order to ensure that the cheapest and most reliable option has been chosen.

The other constraint for this project is time that can be spent on building the prototype. Because our hydroponics system needs to be tested thoroughly, a plant will need to be grown for some amount of time that could be weeks or months. This means that whichever vendor is chosen needs to be able to send a printed circuit board within the first few weeks of the summer of 2014. It is recognized the that successful design and construction of the embedded system onto a PCB in the project is the main criteria for whether or not the project is successful, so with that in mind, the following vendors have been considered for business and are shown in Table 4.1.

Vendor	Website	Minimum Order	Lead Time	Cost per Board
4PCB	http://www.4pcb.com	1	5 days	$33.00
Express PCB	http://www.expresspcb.com/	2	10 days	$300.00
Imagineering Inc.	http://www.pcbnet.com/	1	5-7 days days	$25.00 - $50.00
PCB4Less	http://www.pcb4less.com/	-	5 days	-
PCB Express	http://www.sunstone.com/PCBExpress	1	7 days	$43.00
Ultimate PCB	http://www.ultimatepcb.com/	1	5 days	$250.00

Table 4.1: Comparison of Different PCB Vendors

The vendors that have been found for this hydroponics project are summarized below.

4PCB - The best option for engineering students who are looking for a generic printed circuit board fabrication, 4PCB allows students to order a single two-layer printed circuit board for the low price of $33.00. There is no minimum amount of boards required during the ordering process, and they have designed this program specifically for engineering students to build their project prototypes with. If more than two layers are needed, the upgrade to four layer boards is also inexpensive, costing only $66.00 each.

Express PCB - Is a company that provides a typical printed circuit board fabrication service. They offer a special service for a package of three mini sized printed circuit boards for only $51.00 plus shipping. This vendor is very expensive and also very slow with the delivery of their product.

Imagineering Inc. - Imagineering Inc. is a professional printed circuit board fabrication company that actually has an introductory offer for new customers that makes an initial prototype cost only $25.00. This is very inexpensive and might be the best option.

PCB Express - This service is run by the company called Sunstone. They offer a value PCB service for small orders, making this vendor competitive with all of the other ones.

4.1.3 Mounting Components

The general techniques that can be used to mount an electrical component to a printed circuit board are general soldering of the component, through-hole soldering, and surface mounting technology. Surface mounted parts in general are much smaller than the previous techniques and should be used when available for the manufacturing of many embedded systems that need to be small in size.

One limitation of through-hole mounted electrical components is that because the device goes through all layers of the PCB, it eats up a large amount of space on the finished device. Some electrical components have axial leads, while others have radial leads. The difference between the two affects the way they are mounted, and, generally speaking, radial components are able to be mounted easier in manufacturing processes due to their standing up position on the board. An advantage to using through-hole technology over surface mount technology is that the components are physically held on with a much stronger bond.

Usually, a surface mount device is much smaller than its through-hole analogous component. This is because of its smaller leads or lack of leads. The mounting process is much harder for surface mounted devices, however, due to the very miniature sized parts that make hand soldering much more difficult. One common method of surface mounting is by using a screen printing process with soldering paste and then melting the individual electrical components onto the printed circuit board with a machine that can place the parts extremely precisely with the use of vacuum attachment points. There are companies that offer this pick-and-place mounting machine, and the reflow soldering oven that melts the pieces onto the board. Another advantage to using surface mounted components over through-hole components is that parts can be mounted on both sides of the printed circuit board, allowing the device to save more space.

There is also a facility in the electrical engineering senior design lab that is managed by the Amateur Radio Club at the University of Central Florida which offers students the ability to learn how to use the pick-and-place machines themselves, and also use the reflow soldering oven to connect the pieces.

4.2 Parts Acquisition and Bill of Materials

A summary of the parts that will be purchased during the development and construction of this hydroponics project is shown below in Table 4.2.

Part	Cost
Atlas Scientific Pre-Assembled Female BNC	$8.00
Atlas Scientific ENV-40-EC Probe	$79.14
Atlas Scientific EZO Conductivity Circuit	$43.00
Atlas Scientific Pre-Assembled Female BNC	$8.00
Atlas Scientific ENV-40-pH Probe	$53.21
Atlas Scientific pH Circuit	$28.00
Atlas Scientific ENV-TMP	$18.00
Vishay Silicon NPN Phototransistor	$0.50
Water Level Float Switch	$5.00
Kerick Valve	$8.37
Thomas SR 10/30 DC Peristaltic Pump	$56.94
Nylon Tubing	$0.18 per foot
Thomas 3003 VD LC Diaphragm Pump	$56.94
Hydro II Sponge Pro Filter - Up to 20 gallons	$9.94
Nylon Tubing	$0.18 per foot
FIBOX PC 17/16-L3	$52.73
Botanicare 20 Gallon Reservoir Bottom Only	$46.54
Botanicare 20 Gallon Reservoir Lid	$32.70
Net Pots (Growing Baskets)	$1.00 each
Hydroton Pebbles (Growing Medium)	$10.00
Panasonic LC-X1220P Battery	$61.00
Multicomp MC-SP20-GCS	$187.62
Solarland SLB-0103	$76.00
SolarMagic SM3320-BATT-EV	$159.08
RN-131C Wi-Fi Module	$36.92
Arduino Leonardo Development Kit	$24.95
Atmel Atmega32u4-MU	$6.21
Omnivision OV07690-AL9A	$15.00

Table 4.2: Parts for the Entire Hydroponics System

Chapter 5

Prototype Testing

Now that considerations have been made on how the prototype parts will be sourced and assembled, a plan needs to be made about how the prototype will be tested. The testing process will ensure that the prototype constructed works properly, and achieves all of the goals and maintains the specifications laid out in the first chapter.

The testing procedure will commence as follows:

1. A test environment is chosen so that variables influencing the operation of the device are controlled.

2. Each major subsystem is tested on its own to verify that it performs its own duty correctly.

3. The entire system is tested together to ensure that all of the interfaces are working properly when the whole device is operational.

4. The prototype is then evaluated to see if it performs all of the designated goals and objectives to satisfaction.

5.1 Hardware Testing

The following section contains an overall look at the hardware testing plan, in order to ensure that the final prototype's hardware subsystems achieve all objectives and fits all specifications that have been designed.

5.1.1 Testing Environment

There are two primary locations for the hardware testing of this hydroponics system. The first is the senior design lab that contains electrical equipment that can be used to debug any errors with the electrical connections and interfacing of devices with the microcontroller. The second location is a warehouse owned by one of the team members that contains equipment which can be used to build the housing enclosure and reservoir subsystems.

When running tests on the hardware subsystems, the environment needs to be controlled so that unwanted variables do not influence the operation and fulfillment of the test plan. The list of criteria that the hardware environment must successfully obtain are:

- Protect the device from other people who might be curious about the device and cause it to fail accidentally.

- Isolate the devices from weather conditions that exceed designed limits of the device, such as hurricanes or extreme rain.
- Provide an adequate amount of sunlight for the plant as it grows according to its test plan.
- Supply a stable power supply in the event that an external power supply is deemed necessary.

5.1.2 Subsystem Unit Testing

In the following section, each subsystem's test plan is discussed and listed to provide a summary of what needs to be done to ensure that each device subsystem is working properly.

Power Supply - Product testing is an essential part for any design to be sure that the finished product will work the way it was intended to work. To develop a strategy for testing the power system, the overall objectives for the system must be considered. The power system's main mission for the hydroponics system is to provide power to all of the different parts which includes the microcontroller, pumps, camera and other sensors. It is important that this is accomplished without doing damage the battery by overcharging or deep discharging the battery. The charge controller must work to turn off the current from the solar panel once the battery is fully charged. Since the charge controller is of such high importance to the rest of the system, it will be the main focus of testing for the power system.

The battery, charge controller, and solar panel must be connected together to test the power system for the hydroponics system. The power system needs to effectively charge the battery with the solar panel and then the charge controller can cut off the charge coming into the battery when battery is fully charged.

The solar panel is tested to check that it is working properly during normal operation in direct sunlight during the day. The solar panel must always output 17 Volts during this time to effectively charge the battery in the power system. This is easily tested by exposing the solar panel to sunlight outside and measuring the voltage of the solar panel. It should consistently have a voltage of 17V to be working properly. The battery should be tested for powering the hydroponics system during an entire 24 hour interval to be sure the system will stay powered. This test will be conducted by leaving the fully charged battery alone for a 24 hour interval and then measuring the voltage with a multimeter. If the voltage is still at 12V then the battery will stay charged for 24 hours.

After connecting everything together with the solar panel power coming into the battery the current and voltages of the battery and solar panel can be tested. If there is current going into the battery then the solar panel is charging the battery correctly and it works.

The next thing to test would be the charge controller so all conditions to be tested to ensure it is operating correctly. These conditions include initial start-up, the battery is fully charged, and the battery begins charging. When the device is started the charge controller should check the status of the charge on the battery first to determine if it needs to start charging. So input power into the solar panel side of the circuit is applied and the microcontroller unit is turned on which will tell the charge controller what to do. The battery was not charged so the charge controller should choose to charge the battery. This is tested by measuring the current coming into the battery with a standard multimeter. If there is current present coming into the battery then it is being charged. After the battery has been fully charged, current should cease to flow and the battery will stop being charged. This should happen when the voltage on the battery reaches 12V. Next, the battery will discharge some of its power and the charge controller should begin charging the battery again at this time.

Another test for the charge controller is the condition when the solar panel voltage is lower than the battery voltage. When this happens the start-up circuit should turn on and the output will be PWM with an increasing duty cycle. The start-up circuit will create a current into the battery by with a PWM signal. This is tested with an oscilloscope to measure the output signal is correct with the duty cycle increasing to about 50%. This test will ensure that the start-up circuit part of the charge controller is working properly.

This will conclude the testing on the charge controller, battery, and solar pane that make up the power system for the hydroponics system. These tests will verify that the prototype power system is working and no additional test need to be conducted. A listed design procedure is shown below to show the correct order to conduct the power system testing.

Design Procedure:

1. Test that the solar panel produces enough charge in sunlight to fully charge the battery. If voltage is produced by the solar panel, then it is working.

2. Test that the battery provides power for 24 hours after being charged. Fully charge the battery and measure the voltage on the battery while being discharged by a predicted amount.

3. Connect the solar panel and the battery to the charge controller using copper wiring.

4. Test the charge controller start-up phase by turning on the charge controller and checking that it begins to charge the battery through the solar panel.

5. Wait until the battery is fully charged and then check that the charge controller stops the charging cycle to keep the battery from becoming over-charged by measuring the voltage.

6. Test the power system when the solar panel voltage is small during low light conditions.

The power supply system consists of the following subsystems:

Battery - The battery is rechargeable, and different things need to be considered in order to make sure that the device is working properly.

Some typical questions that might be asked when testing a battery are:

1. Is the device able to fully charge?
2. How much charge is currently in the battery?
3. Is that battery performing to the specifications set by the vendor?
4. Is electrical noise being generated by the battery?
5. Are the safety components of the battery working properly?
6. Has the performance of the battery decreased over time?
7. How many cycles of charge will the battery last through?

In order to preserve the life of the battery, indirect measurements need to be taken about the parameters of the batteries health. For example, the direct way to measure the state of charge of a battery is to fully discharge the battery and measuring the total energy output. But, since every charge cycle damages the health of the battery, this test would shorten the battery life. In addition, the state of health could be measured by cycling the battery cell until it dies, giving the lifespan of the battery. This is undesirable because the device is destroyed in the process.

Using equipment, different parameters can be measured about the performance of the battery. Parameters that should be measured include:

- Internal Resistance - This is necessary to know the power loss that will occur in the battery cell.
- Open Circuit Voltage - This parameter does not provide a reliable measure of the health of a battery, but it can be used to determine the internal resistance of the battery.
- State of Charge - This parameter measures the amount of energy remaining in a battery, which is a fundamental figure of merit for battery devices.
- State of Health - This parameter measures the response of the battery, and how long it will last.

If any of these parameters are shown to be inadequate for the design specifications of the hydroponics project, then a new battery needs to be purchased that does match the specifications.

Solar Panel - In order to test that the solar panels that have been ordered are working properly, certain figures of merit need to be measured and verified with the specifications of the project. This includes:

- DC Voltage - When applied to direct sunlight, a DC voltage is generated by the solar panels that can be directly measured with a multimeter.
- Amperes - The test for amperes of the solar panel is also used with a simple multimeter, but the test should not be done in direct sunlight. Doing so will cause a shock that will damage the solar panel. Instead, the multimeter should be attached to the terminals beforehand, and then it can be moved into sunlight to measure the amperes.

Charge Controller - The charge controller acts as a regulator for the current that charges the battery. In order to test the regulator, the solar panel should be first connected directly to the battery, and tested to see the response. The device must then be hooked up through the regulator and different parameters are then measured:

- Operating Current - The operating current of the device is measured with a multimeter to verify that the battery is being charged correctly.
- Operating Voltage - The operating voltage of the device is also measure using a multimeter to verify that the battery voltage is being regulated correctly.

AC to DC converter - The AC to DC converter is a device that converts the AC power signal of a standard 120V 60Hz wall socket into a DC power supply that the micro-controller and other devices can use to be powered from. This is made from a simple transformer to bring down the voltage of the AC signal, and a rectifier to turn the AC signal into a DC signal. Another feature could be a protection against power surges into the device.

The test plan for this device is to measure the output voltage and output current when the device is connected into a standard wall outlet. The AC to DC converter should bring the voltage down to the same levels as the solar power battery would be operating at.

Main Control Unit - The primary method of control that exists in this project is contained within the main control unit. This is the actual device that houses all of the electrical components. Devices contained in the main control unit are:

- Two Peristaltic Motors
- One Diaphragm Motor

- One Printed Circuit Board
- An Electrical Conductivity Sensor
- A pH Glass Electrode Probe
- A Temperature Probe
- A CMOS Image Sensor
- A water level sensor

First of all, the motors contained in the device are all simple DC motors that can be verified to be working correctly with a power supply and digital multimeter. Test conditions for the peristaltic motor are making sure that the correct amount of fluid is flowing through the device when certain amounts of power is supplied, and making sure that the device does not overheat during use.

The second system that needs to be tested is the interface connections between the sensors and the microcontroller. These can be tested by giving test conditions to the sensors and verifying that the response signal changes appropriately with a multimeter or oscilloscope.

pH Sensor - Calibrate the sensor using two reference solutions before beginning to use the device. Once the device is calibrated, connect it into the circuit which will change the voltage signal values into a digital UART signal, and verify the values the the microcontroller is reading.

Electrical Conductivity Sensor - First, the sensor must be calibrated using a known reference solution. After the device has been calibrated, it can be connected to the circuit which analyzes the electrical response of the probe. The device should then be interfaced with the microcontroller over UART to verify that the values it is receiving are correct.

Water Level Sensor - The water level sensor is a simple switch device that can be measured directly with a meter. The device should be mounted and installed and then tested to ensure that it operates correctly when the water level fills up to the designated level. It is then double checked to make sure with the microcontroller by looking at the values that are being returned by the ADC in the microcontroller.

Temperature Sensor - The temperature sensor is an analog signal device which can be directly measured with an oscilloscope or digital multimeter. The temperature can be measured in a liquid and then verified by using the meters. The device should then be mounted and installed with connections to the microcontroller to verify that the device is returning proper values through the built in ADC of the microprocessor.

Image Sensor - The image sensor is tested by using the device to send picture data to the mirocontroller. The device must be interfaced according to the documentation provided for the sensor, which occurs over UART or SPI. Once the images are taken, then can be sent to a computer to be displayed and verify that the sensor is working correctly.

Phototransistor - The phototransistor is a simple transistor circuit that works similarly to the temperature sensor. The device must be installed and mounted onto the device enclosure, and then tested with a multimeter to verify that the output voltage signal of the device correctly responds to changes in light intensity. The device must then be connected to the microcontroller and verified to work with the built in ADCs of the microprocessor.

5.2 Software Testing

With many of the project features being implemented through software, the software testing methodology and procedure is an important task to ensure accurate function of the project. Software testing can be done in any environment as long as a Wi-Fi network connection is possible. For this software testing, no external materials (except a stopwatch) will be needed because values for different testing functions can be simulated through software. The software testing is broken down into the main components. These components are the system itself, the server, the user application, and the database. Testing is performed on each to ensure proper functionality.

5.2.1 System Testing

Testing the system is the most important testing that needs to be done. Upon completion of the project, the system should be able to function by itself without the need for a connecting server. Some users may not have a connection to a network or may choose not to use this functionality. For this reason, the system needs to be setup in a way that errors in connection to a network do not interfere with sensor testing, correction, and overall operations. If at any point the system loses connection to the server or network, functions that attempt to send information will be skipped over to avoid program crashes and stalling. To test the system, it will be broken up into main functional unit tests. Each unit test will be performed two times: one using the Arduino Leonardo development board, and another using the final created PCB board. During normal operation, the system will run sensor tests every 25 minutes. During these unit tests, no such delay will occur and tests can be performed consecutively without interruption. The unit tests are described below. An assumption is made that a basic server is up and running that can be used as a debug tool. Test values will be sent to the server in post requests. The server will extract the data and print test values to the console for verification of expected test results.

Initial Setup - The initial setup phase occurs when the system is turned on. A few important steps need to be tested in this step. First, hardcoded Wi-Fi settings need to be tested. Once the settings (including server IP and port) are configured in the Wi-Fi module, a ping is sent to the server. If the ping is successful, the system should turn on the pin where the Wi-Fi LED is located. This can be verified by visual inspection of the LED being lit. This result signifies that the system is properly connected to a network and the web server. The next step is to shutdown the system and server and run the test again. The system reloads all of the Wi-Fi settings again and attempts to ping the server. The Wi-Fi LED can verify a successful connection to the network and failure to ping the server. The initial setup will be configured that the Wi-Fi LED will blink for 15 seconds for this occurrence. The last step of this test is to shutdown the system and the Wi-Fi network. The system will startup and indicate no connection to a network by the Wi-Fi LED blinking for 3 seconds and then turning off. By running these tests, a conformation of a positive or negative connection to a network and/or server can be verified.

Load Thresholds - This test is needed to ensure proper EC and pH threshold values are used in sensor tests and analysis. Default values will be hardcoded into variables in the system's memory. User variable values are also set to the default values upon system setup. At any time, EC and pH values can change depending upon the user's interaction with the website. The user can specify which plant they are growing and the server will send these plant specific values to the system. When this occurs, these values will be stored in separate user variables on the system. Upon each execution of this function, default EC and pH values will be checked against the user variables. If they are not the same, the default values are updated to reflect the user variable values. To test this process, the system is first run with the default values. After the value comparison, a post request is sent to the server for verification of these values. The next step is to manually change the user variable values. This manual step enables verification of proper function without having a user application and database up and running. After the comparison, the values are sent to the server for conformation of the change.

Power Test - The power is the next unit block to be tested. The power test is used to verify the power mode of the system and is executed directly after loading threshold values. The system is hardcoded with the low power threshold value upon system setup. In low power mode, the system will not perform any sensor tests or send results to the server. It is very important to accurately test and ensure the system is in the proper mode. To perform this test, a hardcoded voltage value is loaded into the program memory. This value will represent the value received from the battery's charge controller and allows easy testing with different voltage values. The power function does a comparison of the inputted value to the stored threshold value. If the value is above threshold, the system will continue on to sensor testing. If the value is below, the system will send a low power message to the server and enter an idle state for 25 minutes before looping back to the load threshold function. For the first test, a hardcoded value above the minimum threshold is entered. After the comparison to the threshold value, the power LED will blink for three seconds, which indicates a voltage value above threshold and a continuation on to sensor testing. Another test follows where the voltage is hardcoded below the threshold value. The result is verified by the power

LED blinking for 15 seconds and a low power message sent to the server. In the low power state, a program path is taken that will loop back to load thresholds and then to the power test again. This can be verified by visually looking for 15-second intervals of the power LED blinking and by inspecting received messages by the server.

EC and pH Tests - The process for testing the EC and pH functions are identical. Similar to the power test, hardcoded EC and pH values are used in this testing procedure that will represent actual values from the sensors. Both the EC and pH functions keep a counter variable that represents the number of consecutive tests with sensor values outside the threshold range. The counter is used to determine if the system is out of nutrient or pH down fluid. If the counter reaches four or more, an assumption is made that the system is out of fluid because four consecutive tests have been performed without the EC or pH being adjusted into threshold range. For the first test, a value is hardcoded within the minimum and maximum threshold values. To verify the functions take the right action and continue on to the next test, the status LED is used. A value within range will reset the counter to 0 and cause the status LED to blink for three seconds. A test message is also sent to the server that incudes the counter variable's value. This value will be verified and should be 0. Next, a test will occur with a value below the minimum threshold. In both the EC and pH, the proper action is to add one to the counter and run the EC or pH correction functions. To test this action, the status LED is used and will blink for 15 seconds to indicate a value below minimum threshold. A message will be sent to the server with the counter to verify it has been changed to one. The same test will be done for a value above the maximum threshold but the status LED will blink for 30 seconds to denote a difference from the previous test.

After these tests complete, another final test is performed. A value outside the threshold range is loaded and the EC or pH function is looped to run four times. On the fourth iteration, the counter should be four. When this happens, the EC or pH senor value is changed to 0, which notifies the server of the liquid problem. To verify this action, the status and power LEDs will blink for 10 seconds and a message will be sent to the server with the counter and sensor value. The counter should read four and the sensor value 0.

Phototransistor Test - The phototransistor test is an important test to ensure proper camera use. Using the phototransistor, the camera will only take pictures when there is enough sunlight. Like the previous tests, a hardcoded transistor values will be used to easily test with. First, a sensor value outside the threshold range is used. The correct function path should be the one that bypasses the camera operation. This can be verified by using the status LED. The status LED will blink for 15 seconds denoting that the sensor value is low and an image will not be captured. The next test will use a phototransistor value within the threshold range. This should trigger the camera function to run and can be verified by the status LED blinking for three seconds.

Camera, Water Level, and Temperature Test - The camera, water level, and temperature values are all values that are sent to the server and have no impact on the decisions the system makes. To test the water level and temperature sensors, hardcoded values are loaded into the program and a request is sent to the server upon completion of each respective function. The post request will include the sensor information and will be printed to the console for conformation of accurate transmission. The camera function will first take an image, and then send this image to the server. Verification can be achieved by viewing the image sent to the server.

EC and pH Correction Test - The process for testing the EC and pH correction functions are identical. The EC and pH correction functions use the peristaltic pumps to add adjustment liquid to the reservoir. The amount of liquid added is dependent upon the level of adjustment needed, the amount of solution in the reservoir, and the specified product mixing ratios. Providing an accurate amount of adjustment is crucial in ensuring the reservoir maintains proper levels without multiple adjustments needed on consecutive sensor tests. Once an equation is developed from the above dependencies, a sensor value outside the threshold range will cause the pumps to run for X number of seconds. To test these correction functions, a hardcoded EC or pH value out of accepted range will be loaded into the program. The functions will then be run and the status LED will turn on for the number of seconds that the pump should remain active. A stopwatch will be used to measure the time the LED stays on. This test will be run 10 times with the same hardcoded out of range value. Table 5.1 below shows the chart that will be used to perform the test.

EC and pH Correction Timing Test				
Trial Number	**Hardcoded Value**	**Calculated Time (sec)**	**Measured LED Time (sec)**	**Difference (sec)**
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				
10.				

Table 5.1: Fillable Timing Tests for Determining Peristaltic Run Time

By doing hand analysis on hard coded value used, the calculated time the pump should stay on is compared to the time the LED stayed on. Using the results gathered in the table above, the test is considered a pass if the measured time is within two standard deviations of the calculated time.

5.2.2 Web Server Testing

Testing of the web server is an important step in ensuring the proper function of the system. Data sent to the server must be analyzed properly for the user to be able to view it online and be notified when needed. Testing done on the server is much easier than the system because the server can print values to be viewed in the console. Server testing will happen continuously throughout the development process. As new functions are created, the will be individually test and then tested when integrated into a large component. Sever testing will take place on the local Wi-Fi network that the server is connected to. A group member will run the server from his laptop. The only materials needed are a computer and a database running along with the server. The main functional units of the server are broken down into the components shown below. Each will describe a methodology for testing. Testing the web server will be done without the use of the system. Incoming requests from the system will be generated using a web browser instead.

Extracting Data - Incoming requests to the server will be of two types: a low power request and a request with sensor data. Extracting the data into variables is a simple but important step. To test this, a custom post request of each type will be sent to the server using a web browser. The data will be extracted into variables are printed to the console to verify accurate extraction.

Storing Data in the Database - Once the data is extracted, it is important that it is correctly sent to the database. This can be tested easily by using the mongoose API in Node.js to access the MongoDB. First, a connection to the database will be established. Using the console log, any error messages will be indicated. Once a connection is made, sample data from a request will be entered into a function that saves the data in the database. If no error message is returned, the data was successfully stored in the database.

Checking Timestamps - The server will check timestamps during the idle state and while handling an incoming request. During these two different times, the server is focusing on different aspects of the timestamp.

During the idle state, the server is checking each system's most recent timestamp stored in the database against the current timestamp. If the most recent timestamp stored is greater than two hours from the current timestamp, the user is notified of a loss of power or loss of network connection. To test this functionality, a test timestamp will be created and stored in the database. This timestamp will be for more than two hours from the current time. The server will then perform this function. Using a test email and checking for a notification can verify the results. Also, a Boolean test flag can be used and printed to the console to verify the path taken.

During an incoming request, the server is comparing the incoming data's timestamp to the oldest timestamp stored for that device. If the incoming timestamp is more than 45 days after the oldest timestamp, the plants have reached an adult stage of growth and their EC values will increase. To test this procedure, a sample oldest timestamp is stored in the database that is more than 45 days ago. When this procedure is executed, the server will initiate the change in EC and display a console message for verification. This process is dependent upon two factors. These factors are: user identification and user plant specification. Depending upon whether the user is registered and/or specified a plant they are growing, the end EC values will be different. Table 5.2 below summarizes the different possibilities are the expected outcome.

Registered	Plant Type Specified	Expected Output
YES	YES	Values Stored in the Database
YES	NO	Default Values
NO	N/A	Default Values

Table 5.2: Summary of Adult EC Output Values Depending Upon User Data

This process first uses the incoming request device ID search for the corresponding user in the database. If a user is found, a check is done on the user record to look for plant specific input. If input is found, the plant type is search in the plant database documents for the adult EC values. The default values are constants that are predefined and general for all plants. In all cases where the user does not specify a plant type being grown, the default values will be used. All three different variations above are tested. The EC results from each are printed to the console and verified against the table above.

Notifications - Email and text notifications are important features on the product and testing is done to ensure proper delivery. Emails will be sent using the email specified by the user during registration. Different emails will be sent depending upon the type of notification required. The mailing process is the same for each type with the message body being different. A test will be performed that sends a test email using each of the different notification messages. To ensure successful transmission of the email, the user's email will verified during registration for a valid format. Any email address that don't exist or have an incorrect format will trigger an error message to be printed to the console and message delivery will fail. The server will be setup in a fashion that the error will not cause the server to crash or stall. Once an error is received, the message will be displayed on the console and the server will continue with its next task.

Text messages will be sent using the same email functions. Each cell phone carrier has an SMS gateway address that allows users to send messages to phones directly by using a carrier specific address. The format is XXXXXXXXXX@phone-carrier.com, where the X's represent the 10-digit phone number. Table5.3 below specifies the carrier specific formats that will be used [26].

A test will be performed for the different carriers used by each group member. The test will append the user phone number with the gateway address and send text messages for each different type of notification message. Since this process will use the same email functions, and error in delivery will be printed to the console and not impede

Phone Carrier	SMS Gateway Address
Alltel Wireless	XXXXXXXXXX@text.wireless.alltel.com
AT&T Wireless	XXXXXXXXXX@txt.att.net
AT&T Mobility (formerly Cingular)	XXXXXXXXXX@cingularme.com
Boost Mobile	XXXXXXXXXX@myboostmobile.com
Cricket	XXXXXXXXXX@sms.mycricket.com
Metro PCS	XXXXXXXXXX@mymetropcs.com
Sprint (PCS)	XXXXXXXXXX@messaging.sprintpcs.com
Sprint (Nextel)	XXXXXXXXXX@page.nextel.com
Straight Talk	XXXXXXXXXX@VTEXT.com
T-Mobile	XXXXXXXXXX@tmomail.net
U.S. Cellular	XXXXXXXXXX@email.uscc.net
Verizon	XXXXXXXXXX@vtext.com
Virgin Mobile	XXXXXXXXXX@vmobl.com

Table 5.3: List of Phone Carriers and Corresponding SMS Gateway Addresses

other server tasks.

5.2.3 Application Testing

The application is important to test because the user will use it directly and is necessary in setting up accounts for notifications and viewing sensor data. The application is a website that is running on the web server. The application testing is divided into the main functional units below.

Registration - Each user must register and create an account before accessing sensor data or changing plant settings. Users must enter an email, password, name, device ID, phone carrier, and a phone number. User email addresses and phone numbers must be checked for accurate formatting. Using regular expressions, these fields will be checked upon submission of the information. To test user registration, sample accounts will be made with a variety of information in different formats. Verification of accurate entries will be printed to the console. Any information entered with an incorrect format should prompt the user to change the affected fields.

Authentication - User authentication is necessary for the application to display the correct data and views. Using a Node.js module called passport, each user's session, login, and logout can be ensured. To test authentication, the user's login credentials are checked against the database. If not found in the database or the information is incorrect, the user is redirected back to the login page. A test will be performed with correct and incorrect data to verify an accurate login.

The user can only access the sensor data pages if they are logged in and have an active session (i.e. not closed the browser). To test this, each sensor data page URL will be entered into a web browser without a user being logged in. The proper action is a redirection to the welcome page. Then this test will be performed after a user has successfully logged in. The user should have access to each sensor view page.

The last test is to ensure proper logout. A test user will be logged in and verify that all of the sensor data pages can be accessed. Next, the user will logout and attempt to access the sensor pages by directly entering the URL in the browser. This should redirect the user to the welcome page. A second test will be performed where the user will close the web browser while logged in. Upon opening the browser again, the user should only have access to the welcome page and be asked to log in again.

Sensor Data Pages - Time permitting, there will be several sensor view pages. One will be in graph format, one in a list view, and one in a search view. Testing will be done on each to ensure proper formatting and proper data pulled from the database.

5.2.4 Database Testing

The database testing procedure is straightforward and simple. Using the command line, a test will be performed that starts the database running, populates the different database tables and runs a query that shows all of the information in the database. Verification that the data is stored in the correct format and structure will ensure proper database functionality.

5.3 Integration Testing

Once the individual subsystems have been tested to work independently of each other, the entire system must be assembled and interfaced together. This type of testing is known as integration testing because the device is being integrated together.

The main things that need to be verified in integration testing requirements are:

- The microcontroller correctly interfaces with all data sensors and can display them one after another during intermittent timed test procedures.
- The microcontroller sends data over Wi-Fi signal that correctly interfaces with a web server and displays data that can be viewed on the website.
- The microcontroller can correctly operate all of the various pumps and send varying amounts of fluid into the reservoir system.
- Any specifications about the device operation should be verified to still be functional during the integration testing.

5.4 Product Evaluation and Conclusions

In order to properly evaluate the success of the design of this hydroponics system, the final prototype must be compared against the initial goals and objectives that the design set out to accomplish. The final goals and objectives that the device must maintain are:

Power Supply - The power for the hydroponics system must be generated by solar panels or by the use of an AC wall socket. A 12V battery attached to the device stores the power from the solar panel, and then delivers it through a voltage regulator to the microcontroller and other isolated components that also need a power connection.

Control - The microcontroller is able to analyze data that it recieves from the various sensors around the device, and then interpret this data to be able to make decisions about.

Communications - A live internet connection is achieved with the Wi-Fi transceiver module. The microcontroller is able to interface with this device and send data to a local server to be displayed onto a web page for a user to operate.

Sensors - Many different sensors are interfaced with the microcontroller. The properties that the microcontroller are able to measure include:

1. pH Level
2. Electrical Conductivity
3. Water Level
4. Water Temperature
5. Light Intensity
6. Image Sensor

Hardware - The hardware of the system is durable and supports all aspects of the device. It includes:

1. A proper growth environment for two plants.
2. An air pump and filter comibination.
3. Two liquid dispensing pumps for nutrients and pH solution
4. A housing enclosure to protect the electrical components of the device.

Software - The system employs the use of an external companion website that allows the user to change configuration options of the system. The system displays graphs that indicate the health and progress of the plants being grown. The user is able to look at picture updates of their plant as it grows in the hydroponics syste.

The final evaluation of the project is based on the idea that the device actually does help to grow plants faster than traditional soil based approaches. In order to test this aspect of the device, a control plant is planted in soil and then the hydroponics plants are tested at the same time. Daily observations will be made about the health of both plants, until finally a conclusion can be made about the successful operation of the hydroponics project.

Chapter 6

Administration

Now that the hydroponics project has been researched, designed, and a plan for building and testing the prototype has been completed, tasks related to the administration and management of the project are presented.

This chapter includes:

1. A schedule for the completion of the project using major milestones as a guideline for staying on track.
2. A budget discussion that includes an itemized cost of the project, as well as where funding has been acquired for the completion of the hydroponics system.
3. A section on management and division of labor among the four group members involved on the hydroponics project team.

6.1 Development Milestones

The following milestone schedules are used to remind the team to keep on track during the research, design, and prototyping phases of this hydroponic system's development. Each member has contributed their own unique talents to this project, and the work load has been distributed as evenly as possible and according to the interests of specific members.

6.1.1 Senior Design 1

Table 6.1 contains milestones and due dates for the first senior design class which consists mainly of defining the problem that this project solves, and researching and designing different techniques that a hydroponics system can use to solve any problems that arise.

Topic	Components	Members	Due Date
Design Goals and Specifications			2/28/14
Research and Design			4/25/14
Hardware	Container, Water Pumps, Soil and Basket, etc.	Mike and Matt	2/28/14
Sensors	EC, Temperature, pH, etc.	Mike and Justin	3/14/14
Control	Microcontroller, web server, etc.	Khalid and Justin and Matt	3/28/14
Power	Solar Panels, Battery	Justin	4/11/14
Finish Design Document			4/25/14

Table 6.1: A Schedule of Milestone Completion Dates for Senior Design 1

6.1.2 Senior Design 2

Table 6.2 contains milestones and due dates for the second senior design class which consists mainly of constructing a working prototype of the designed hydroponics system, and to test the product to verify that it performs to the specifications that have been chosen. The final stage of Senior Design 2 is a professional presentation to an engineering committee at University of Central Florida that consists of professors in the EECS Engineering Department.

Topic	Components	Members	Due Date
Prototype Construction			Week 4
Tests and Evaluation			Week 2
Hardware	Container, Water Pumps, Soil and Basket, etc.	Mike and Matt	Week 3
Sensors	EC, Temperature, pH, etc.	Mike and Justin	Week 4
Control	Microcontroller, web server, etc.	Khalid and Justin and Matt	Week 5
Power	Solar Panels, Battery	Justin	Week 6
Presentations and Demonstrations			Week 7

Table 6.2: A Schedule of Milestone Completion Dates for Senior Design 2

6.2 Budget and Finance

During the initial design phase of this senior design project, a sponsorship funding program, Duke Progress Energy, started accepting applications from students to receive funding for their senior design projects. The criteria for selection was a good initial proposal design that relates the project to sustainability and eco-friendliness. This hydroponics design was sponsored under this program for $765.00, which was the full amount of funding requested. Table 6.3 below shows the predicted financial budget when using the desgin specification and parts listed in the above design chapter.

Subsystem	**Cost**
Electrical Conductivity Sensor	$130.14
PH Sensor	$89.21
Temperature Sensor	$18.00
Water Supply Valve and Sensor	$13.37
Peristaltic Liquid Pump	$56.94
Oxygenation Pump and Filter	$66.88
Device Enclosure	$52.73
Plant Reservoir and Lid	$91.64
Solar Panel, Battery, and Charge Controller	$483.70
Wireless Transmitter	$36.92
Microcontroller	$31.16
PCB Construction	$66.00
Other Supplies	$10.00
	Total: $1146.69

Table 6.3: List of Major Subsystems and Expenses

6.3 Division of Labor

In order to ensure that each group member gained the most educational value from this project, different topics of this projects design and construction have been divided according to work load for each person and the respective interests of the team members.

In order to organize the tasks of each member, the following list has been created. While each group member is ultimately responsible for the success of the entire project, certain subsections have been designated to specific members:

Matthew DiLeonardo - Designated as the team leader, Matthew created the original idea of this hydroponics project. Being already familiar with the fundamentals of hydroponics, due to prior experience, Matthew was able to explain important actions and precautions that need to be taken when running a hydroponic garden. Matthew took the responsibility of educating the group about the science of hydroponics, and also has the skills necessary to focus on the software aspects of the project. His tasks include:

- Reservoir Design - The basic housing that contains the water, as well as the plant roots support system.
- Air Filter and Oxygenation - The subsystem which takes in air from the device to add dissolved oxygen to the water while also cleaning it.
- Nutrient Solutions - Choose which nutrients will be suitable for given plants and their growth stages.
- Software - The web server hosting, microcontroller logic, Wi-Fi communications, user control panel, and system alerts.

In the senior design paper, a significant portion of his work went towards the software research, design, and prototype testing sections.

Khalid Al Charif - Showing interest in the technology of wireless communications networks and the interfacing of the microcontroller and its peripherals, Khalid was given the responsibility of researching communications technologies that could be implemented with given microcontrollers. Khalid also designed different implementations of Wi-Fi transceivers for use in the project, as well as educating the project team on the common interfacing techniques between microcontrollers and peripheral devices. His tasks include:

- Wireless Communications - The design and research of different wireless communications devices, and the program interface between the microcontroller and these peripheral devices.
- Microprocessor - Research into different microprocessor manufacturers, looking at advantages and disadvantages of each.

In the senior design paper, a significant portion of his research contributed to the communications and microcontroller design.

Justin Walker - Showing an interest in electrical circuit design, Justin focused his efforts on the design of the power system and printed circuit board interfaces. Justin was able to research a spectrum of solar and batter technology to educate the group on best practices for this projects design. Justin also researched image sensor devices, and is the primary leader for the image sensing technology on this project. His tasks include:

- Solar Panels, Battery, Charge Controller - The power supply which gives this system the capability of running independently of external power.
- Image Sensor - Implementation of the CMOS image sensor used to send time lapse image updates to the hydroponics system user.
- AC to DC Converter - The system which allows this device to be plugged into

standard wall outlets if solar power is undesirable for the user.

- Microcontroller - Research about different microprocessor manufacturers and the advantages and disadvantage of each.

In the senior design paper, a significant portion of his efforts contributed to the solar power and battery design, the image sensor design, and the microcontroller chosen for this project.

Mike Loomis - With an interest in sensor technology, and the mechanical design of the hydroponics system, Mike focused his efforts on researching different techniques to measure various parameters of water quality to educate the group. Mike also has strong skills with programming and modeling, so the product design and microcontroller technology was a primary concern of his. Mike also serves as the primary organizer of the incoming research and design sections for the various hardware subsystems that exist in the hydroponics project. His tasks include:

- Product Design - The look and layout of the product enclosure, as well as parts acquisition and construction of structural components.

- Sensor Design - The sensor device designs that exist to allow the microcontroller to make decisions on.

- Microcontroller Programming - The embedded programming for the chosen microcontroller.

- Administrative Tasks - Organizing research efforts and design goals for the hydroponics project.

In the senior design paper, a significant portion of his efforts contributed to the hardware subsystem research and design sections, and the formatting of the final paper.

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The Arduino software is also open-source. The source code for the Java environment is released under the GPL and the C/C++ microcontroller libraries are under the LGPL.

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