IPMS: Indoor Plant Maintenance System

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Table of Contents

Executive Summary

As a UCF Senior Design project, the need for an automated device to provide plant care for homeowners is described and justified by various situations. In particular, absent homeowners with plants they value often have no way to assure that they are given the resources they need. An Indoor Plant Monitoring System (IPMS) is proposed as an attractive alternative to other options.

The IPMS will provide the functionality to manage the application of critical light and water resources to unattended plants. This functionality is defined by the system specifications as eliminating on-site manual care, automatically applying resources, operating for an extended period, being adaptable to varied plant needs, having a user interface, sensing environmental conditions, providing remote access, and being easy-to-use.

It is estimated that the marketing requirements include cost, utility, ease of use, reliability, operational duration, durability, and appearance. The system specifications are translated into engineering requirements for power, size & weight, resource utilization rate, design complexity, sensor accuracy, range of operation, and lifespan. These are related to the marketing requirements in a traditional "House of Quality" from which the importance and prioritization of requirements is derived.

The IPMS target engineering parameters require operation for not less than 14 days with better than 90% reliability, have a wide range of adjustment (90%), be produced on a single board weighing less than one pound, and last at least 5 years without failure.

Both a hardware and software block diagram are provided. The basic hardware consists of a ATmega 328 microprocessor integrating sensors for temperature, soil moisture, light, and humidity, plus WiFi and Bluetooth modules for the user interface. Software consists of an internet user interface for setting operational parameters, and microprocessor code to interpret the sensor inputs and operate the controls to apply resources as needed.

The estimated budget for the project is $150-$487. The largest costs are associated with the peripheral items such as batteries, containers, lighting, and fabrication materials needed complete development the system

Specifications are provided for all of the major components. A preliminary design for the software is included. The project schedule provide milestones throughout Spring and Summer of 2021, with project completion in August 2021

Additionally, alternative project ideas are discussed and evaluated.. Finally, the tentative selection of plants for the proof of concept is described.

1. Introduction:

People like to travel and take vacation time to spend with their loved ones. However, many people leave their plants unattended at home in doing so. There have been many self watering plant designs sold that soak the bottom of the plant bowl in order to keep the soil moisture high. These designs don't have any system that monitors how much an individual plant has been watered or how much light it is receiving etc.

Moreover, many people just try to estimate or guess how much water they can put in the pot when they leave the house so that the plant doesn't die. Other solutions would include trying to find someone else to visit the house to water all the plants. Most of the time people just leave the plant to fend for themselves. In some cases people may try to set up their own irrigation system through a do-it-yourself tutorial on "youtube.com".

This is what the Indoor Plant Maintenance System is going to solve. The "IPMS" aims to allow the user access to all this information from anywhere in the world. It is focused on small to medium sized plants that are commonly bought by people around the United States. The hardware of the IPMS will contain several sensors that will collect information on the plant's surroundings and display this information digitally Via WiFi connection.

The WiFi connectivity will allow access to the IPMS from anywhere in the world with any device that can connect to the internet. This allows for a more seamless experience with the IPMS. The circuit board will be waterproof so as to prevent any damage to the circuitry when the sensors attempt to obtain the moisture levels from the soil.

The Indoor Plant Maintenance System is an all in one plant care device. Wherever you are you can manage and monitor the overall health of your plant. Forget to water the plants on the way to work? Water it from the Online Application. This device makes plant care stress free and more consistent.

2. Project Motivation:

Many homeowners like to have some sort of plant(s) inside their home. Plants are self sustaining, but they need to be cared for on a consistent basis when they are outside of their native environment. For them to be kept indoors they still need to get adequate sunlight and hydration. This becomes a problem when there is no one at home to care for the plant. For example, if a homeowner is traveling on business or on vacation with a significant other then their plants at home have no way to take care of themselves.

Often people might call someone they know to go to the house and water these plants, because that is a solution to prevent the plants from deteriorating. Another solution would be to try to use a "Do It Yourself" kit (D.I.Y) which would use household items to create a system for watering plants such as using a water bottle with a thin tube placed in the soil. The problem with this solution is that it is not consistent with how the plant might need to be cared for. The plants are often left alone with a DIY kit being constantly fed with water and nutrients without realizing the plant could possibly be over or underfed.

The person who is called to the house might over water the plant as well as the D.I.Y kit described in online videos.This is because different plants have different needs in terms of care. Some plants may require little water every other day and others might need to be watered constantly to be sustained. To solve this problem the proposed solution is to create IPMS, the Indoor Plant Maintenance System. We want to build a system that can properly care for indoor plants once the homeowner is away.

The Indoor Plant Monitoring System would be able to monitor how much water is in the pot of the indoor plant and be able to apply water to the soil accordingly. The IPMS will have an easy to use interface that the user can interact with. The IPMS will water the plant when the moisture in the soil is getting too low through several sensors as well as be able to tell how much light the plant is receiving on a daily basis. This will let the plant stay hydrated and well lit when no one is in the house to provide proper care.

The Homeowner will be able to monitor their plants through an application that will say how much water is in the plant and allow them to disable the watering or add more water manually through the application. This is so that the owner can adjust the water flow to prevent the plant from being over-watered. This would be the only Indoor Plant Monitoring System that allows the user to interact with the plant through software when they are away.

Another competitive system would be a self watering pot by HBServices who have thousands of good reviews online. They use a pot that lowers the plant into a cup of water on hollow legs so that the soil can soak the water up to where the roots are. The problem with this is that it may not reach roots that are not long even and also prevents an even distribution of water throughout the soil. IPMS would apply water to the top of the soil so that the soil will have moisture all throughout as water is pulled down by gravity.

3. System Specifications:

The system specifications are shown in Table 1 "System Specifications".

Table 1 "System Specifications"

Sr. No	Description
1.	No need for the user to manually keep on checking the plants health
2.	Automatically water the plants when the owner is not present
3.	Power consumption of a wireless sensor network should be less so that it can be used for a long period of time.
4.	The user interacts with the android application and the sensors fixed around the plants will update the current condition of the plant environment.
5.	Precision is providing the environment condition of the plant.
6.	Sensors obtain ambient temperature, ambient humidity, soil moisture and illuminance it to the cloud which is then displayed on the UI on the user Android device.
7.	If the user is facing Internet problems, he/she can easily access using Bluetooth.

8.	The application should have an easy-to-use interface and present data with minimal latency.

4. House of Quality

The House of Quality Analysis is an estimation of the relationship between marketing requirements and engineering requirements. It provides a guide to the establishment of design and performance requirements for the project.

The marketing requirements are the anticipated needs of potential customers or users of our product. These have been identified as the following:

4.1. Cost:

Cost is always a factor. The production cost of the product must be as low as possible to meet the engineering requirements so that it can be marketed at an attractive consumer price.

4.2. Utility:

The product must serve a useful purpose. In our case, it must be able to provide sufficient care for plants that the potential customer feels the cost is worthwhile as an investment. The more utility we can provide, the better our product will be.

4.3. Ease of Use:

The product cannot be too difficult to install or use. In our case, we will need some sort of control box with adjustments for the application of needed plant resources. Sensors must be easily positioned, and the application of resources must be easily adjusted to meet the needs of various plant sizes and varieties.

4.4. Operational Reliability:

The purpose of our product is to provide care for a living thing. If our product fails in any way, the plant in its care may die. Therefore, product reliability is of paramount importance.

4.5. Operational Duration:

Although the product might be used as a routine helper in the home, it is specifically intended for use when the homeowner is away for an extended period, such as a vacation. Our estimation is that this means the product must be able to function without further interaction for at least two weeks, and longer would be better.

4.6. Durability:

The product will come in contact with dirt and water. It will also be moved about from time to time. It must tolerate these conditions. The more durable our design, the longer our product will last, adding value.

4.7. Appearance:

Finally, it should have the appearance of being a reliable product capable of doing the intended functions. Various components cannot appear too fragile, too heavy, or too cumbersome in any respect.

The engineering requirements have been broken down into several distinct categories. These are intended to be functionally independent, but several have likely correlation with other characteristics.

4.8. Power supply:

The product will be electrically powered. The choice of power source and stability of its output is a major factor in the ability of the product to perform its function. The final design will be dependent on the selection of components and their power requirements. Based on our marketing requirements, we have set 14 days as the minimum uninterrupted power availability.

4.9. Size & Weight:

The size and weight of the product affects it's portability and ease of use. We know that smaller and lighter is better, as long as the product retains a solid appearance. We think that a suitable product can be produced weighing less than 5 pounds.

4.10. Resource Utilization:

The product will be designed to apply resources the plant needs to thrive. These are likely to be limited, as in having a finite supply of water, fertilizer, or available light. Therefore, the efficient utilization of these finite resources is an essential requirement. Given our marketing requirement, we have targeted the resource utilization to match the 14 days.

4.11. Design complexity:

For several reasons, the design cannot be overly complex, A complex design will cost more, and be more difficult to maintain. Fewer components means fewer failures. Standardized interfaces will enable more flexibility, adaptability, and enhancement

4.12. Sensor accuracy:

The product functionality depends on being able to detect the essential needs of the plant. The sensors must be accurate enough to provide the inputs needed for management and control.

4.13. Range of operation:

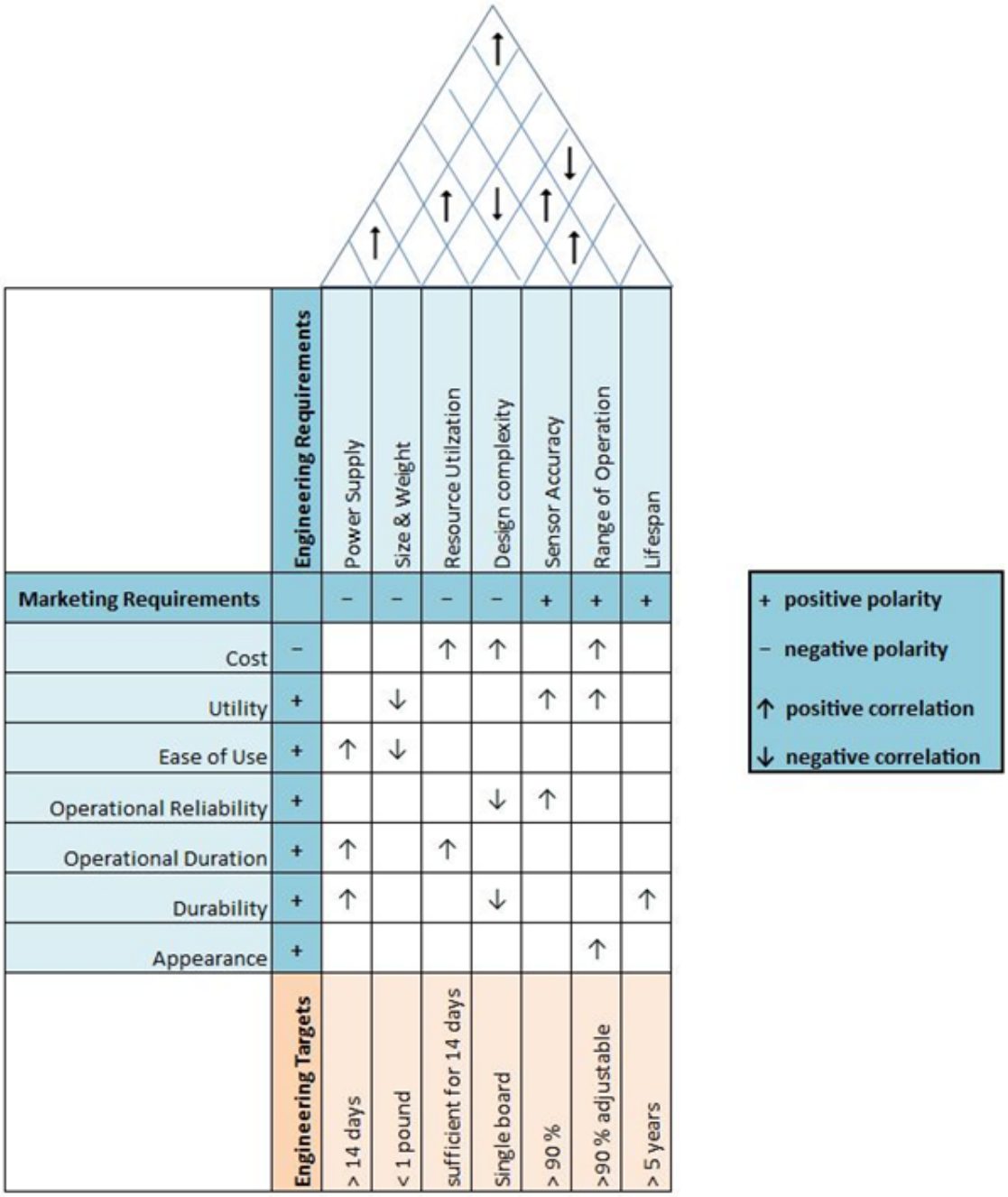
Plants have different needs depending on their variety and size. Additionally, the general environment can impact the management of resources. The product must have the controls necessary to tailor the operation of its sensors and the application of resources to provide the greatest range of application possible.

4.14. Lifespan:

Some components, such as humidity sensors, may have limited lifespan. It is desirable to mitigate the effects of aging wherever possible, or make replacement of parts that limit the lifespan of the product simple to replace.

Given these marketing and engineering requirements, the analysis is summarized in Figure 1, "House of Quality". Correlations between engineering attributes are shown in the triangle at the top. The matrix shows positive and negative correlation between the marketing requirements and the engineering requirement. Target values for each of the engineering requirements is shown at the bottom.

Figure 1: "House of Quality”



5. Hardware block diagram

The hardware block diagram is shown in Figure 2 “Hardware Block Diagram”.

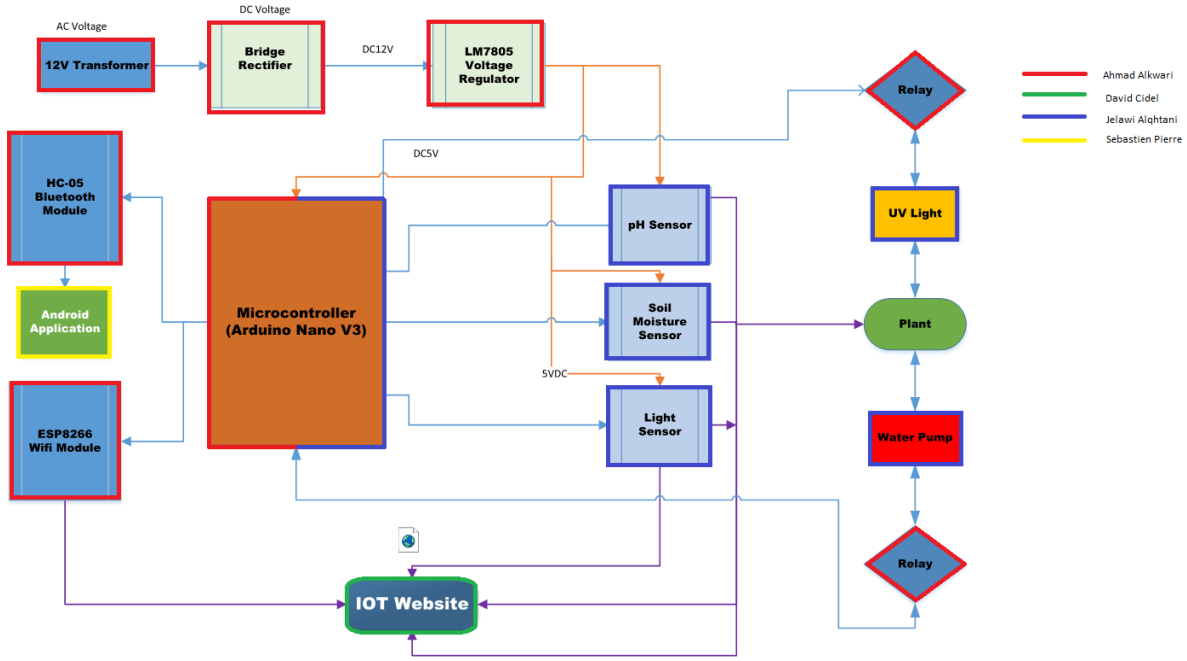


Figure 2: “Hardware Block Diagram”

Roles:

Ahmad Alkwari: Electrical connections and sensors

JelawiAlqhtani: Electrical connections and sensors

David Cidel: IOT Web design

Sebastien Pierre: Application Design

6. Software block diagram

The software block diagram is shown in Figure 3 “Software Block Diagram”.

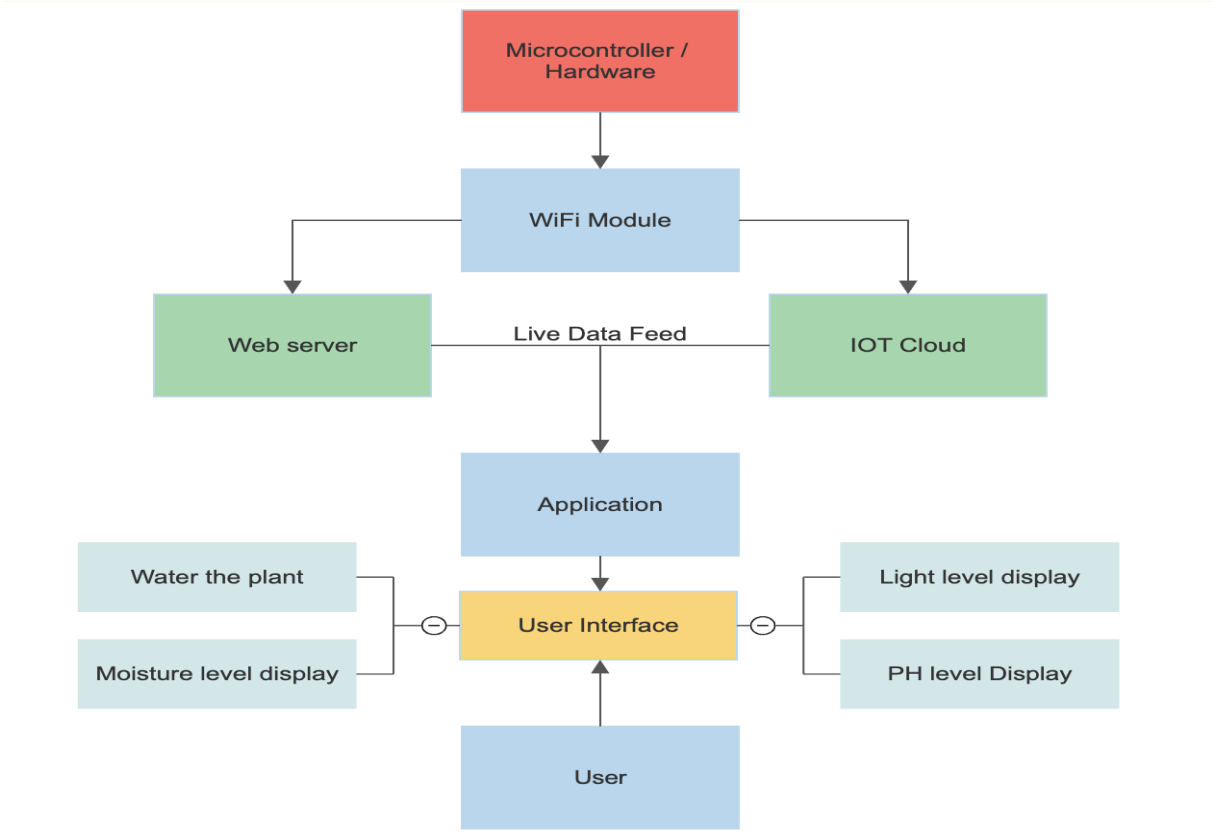


Figure 3: “Software Block Diagram”

7. Estimated Project Budgeting

Overall, without the inclusion of unplanned components or the need to repurchase some items, the initial budget for this project is expected to be between $150.08 - $487.17. With the budget split among the four members of the project, the expected price it will take to complete this project is approximately between the range of $37.52 - $121.79 for each member of this project. This is shown in Table 2, “Estimated Project Budgeting”.

Table 2 "Estimated Project Budgeting"

Device/Part	Approximate Price
SENSORS:	
Soil Moisture Sensor	$7.00-$40.00
Temp/Humidity Sensor (DHT11)	$1.50-$7.00
Light Sensor (LDR)	$6.00-$20.00
PH Sensor	$6.00-$30.00
Electronics:	
CPU	$10.00-$40.00
Microcontroller	$1.00-$15.00
Bluetooth module(HC-05)	$2.00-$20.00
Development Kit	$30.00-$50.00
Wifi Module(ESP8266)	$2.00-$15.00
Circuit Elements:	
Diode(1N5408)	$0.72-$2.12
Diode(1N4007)	$0.06-$1.50
Capacitor (25V)	$0.79-$2.00
Voltage Reg(LM7805)	$0.50-$1.40
Terminal Blocks	$0.99-$1.04
Switch Transistor(BC547)	$0.92-$1.21
Resistors	$0.60-$0.90
PCB	$20.00-$60.00
MISC:	
Batteries	$10.00-$20.00
Container	$30.00-$50.00

LED Lights	$20.00-$60.00
Software Expenses	$0-$50.00
Shipping Expenses	TBD
Approximate Total Price Range:	**$150.08-$487.17**

8. Initial Project Milestones

Table 3 "Initial Project Milestones"

Spring 2021 Schedule

Week	Milestone (Tasks)	Start Date	Deadline
1	Form Group/Brainstorm ideas	January 11, 2021	January 15, 2021
2 to 3	Choose a project and discuss features	January 15, 2021	January 29, 2021
3	Finish Divide and Conquer V1		January 29, 2021
3 to 5	Research and Discuss the details of the project amongst group and Professor.	January 29, 2021	February 12,2021
5	Finish Divide and Conquer V2		February 12, 2021
6 to 9	Study and implement various possible designs for the project	February 12, 2021	March 12, 2021
9	Submit New Assignment on Standards		March 12, 2021
12	Submit 60-page Draft		April 02, 2021
13 to 14	Review Documentation and Finalize both Design and documentation (Spring Break)	April 03, 2021	April 16, 2021
14	100-page Report		April 16, 2021
15	Organize all documents for final submittal and begin purchasing components needed for prototype	April 16, 2021	April 27, 2021
16	Submit Final Documentation		April 27, 2021

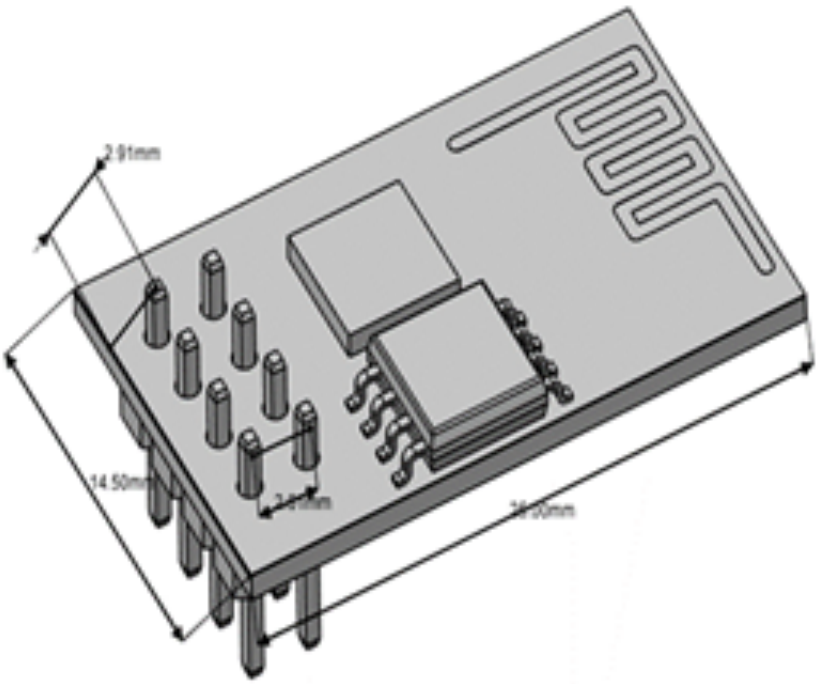
Summer 2021 Schedule

Week	Milestone (Tasks)	Start Date	Deadline
0-1	Acquire Purchased Components & Test them	April 27, 2021	May 17, 2021
1 to 2	Build Prototype	May 21, 2021	May 28, 2021
3	Adjust components and documentation based on prototype results and purchase revised components	May 28, 2021	June 05, 2021
4	Build final product	June 06, 2021	June 12, 2021
5 to 6	Troubleshoot Hardware and Software issues	June 13, 2021	June 25, 2021
6 to 7	Tweak issues based on troubleshoot	June 26, 2021	July 03, 2021
8	Troubleshoot/Test product	July 04, 2021	July 10, 2021
9	Finalize Product	July 11, 2021	July 17, 2021
10 to 11	Complete Documentation	July 18, 2021	July 31, 2021
11	Present Product		August 07, 2021

9. Hardware Components

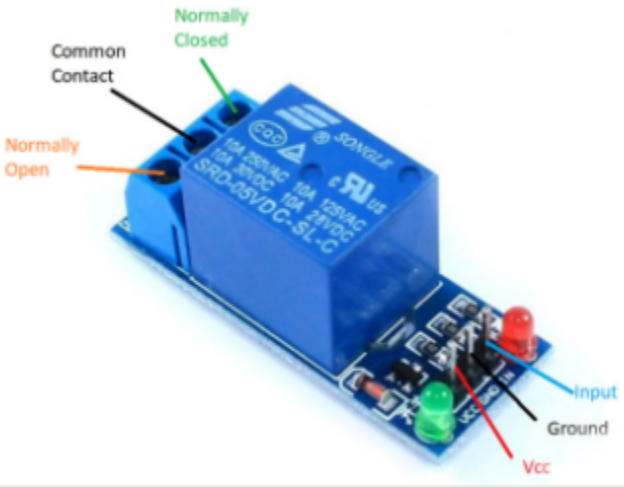
9.1. ESP8266 WIFI Module:

- Power Supply: 3.3V
- Current Consumption: 100mA
- I/O Voltage: 3.6V
- I/O Source Current: 12mA
- Flash Memory: 512KB



9.2. Single Channel 5V Relay Module

- Supply voltage – 3.75V to 6V
- Quiescent current: 2mA
- Current when the relay is active: ~70mA
- Relay maximum contact voltage – 250VAC or 30VDC
- Relay maximum current – 10A

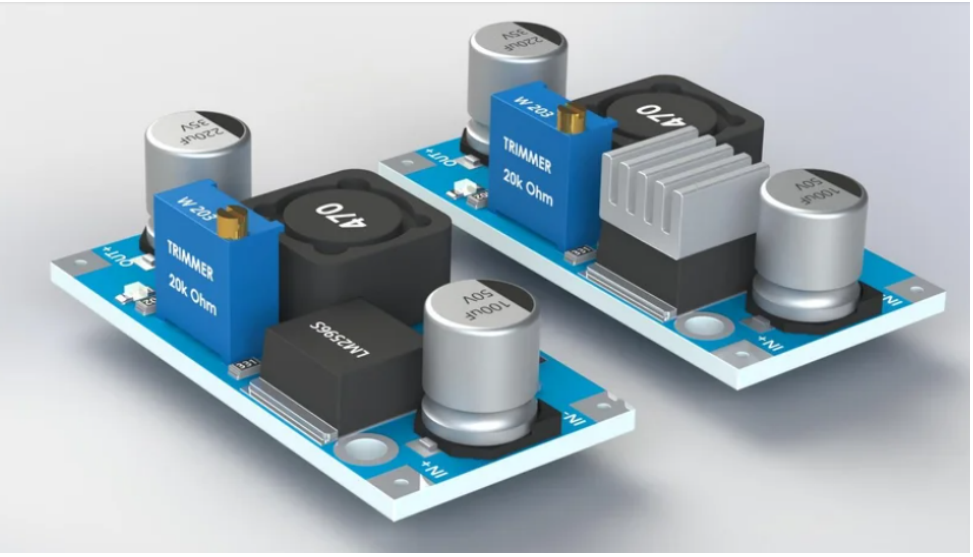


9.3. ULN2003 Module

- Contains 7 high-voltage and high current Darlington pairs
- Each pair is rated for 50V and 500mA
- Input pins can be triggered by +5V
- All seven Output pins can be connected to gather to drive loads up to (7×500mA) ~3.5A.
- Can be directly controlled by logic devices like Digital Gates, Arduino, PIC etc
- Available in 16-pin DIP, TSSOP, SOIC packages

9.4. Buck Converter (LM2596) Module

- Input voltage: 4V-40V DC
- Output voltage: 1.25V-35V DC
- Voltage difference between input and output: >1.5V
- Output current (max): 1A (no cooling), 2A (with passive cooling*), 3A (with active cooling*)
- Conversion efficiency (max): 92%
- Switching frequency: 65kHz
- Output ripple: <30mV
- Load regulation: ± 1%
- Operating temperature: -40°C to +85°C
- Dimensions: 43.3 x 21.0 x 13.5mm



9.5. HC-05 Bluetooth Module:

- Supply Voltage: 3.3-5V
- Working Current: 30mA
- Operating Range: 10 Meters
- Support Baud Rate: 9600,19200,38400,57600,115200
- Dimensions(L x W x H) : 28mm x 15mm x 2.35mm

9.6. Soil Moisture Sensor:

- Operating Voltage: 3.3V-5V
- Operating Current: 15mA
- Output Digital: 0V-5V
- Output Analog: 0V-5V
- PCB Dimension: 3.2cm x 1.4cm

9.7. pH Sensor:

- Supply Voltage: 5V
- Current: 5-10mA
- Working Temperature: 10-50 Degree Centigrade
- Probe Response Time: <2 Minutes
- Noise: <0.5 mV

9.8. DHT11 Sensor:

- Working Voltage: 3.3-5V
- Measurement Range: 20-95% RH ; 0-50 Degree Centigrade
- Resolution: 8Bit(Temperature) , 8Bit(Humidity)
- Compatible Interface: 2.54 3-Pin Interface

9.9. LM7805 Voltage Regulator:

- Output Polarity: Positive
- Output Voltage Type: Fixed
- Output Voltage: 4.75-5.25V
- Current: 1.5A
- Input Voltage: 7-25V

9.10. 1N5408 Diode:

- Forward Current: 3A
- Forward Voltage: 1.2V
- Operating Temperature Range: -65-150 Degree Centigrade
- Number of Pins: 2

9.11. 1N4007 Diode:

- Forward Current: 1A
- Forward Voltage: 1.1V
- Operating Temperature Range: -65-150 Degree Centigrade
- Number of Pins: 2

10. Alternative Projects Considered

10.1. Delivery Alert System:

A device would monitor the front door area and alert the resident when a package is delivered.

Increasing numbers of people are ordering online and getting deliveries. Some of these are food items that may be perishable or attract animals. There is also an increasing number of thefts. The device would use a scanner like a garage door safety system, with one or more mirrors positioned to effectively cover the front porch area where a package might be left.

The system would include a timer to determine that an object had been delivered, and alert the resident. It could be entirely self-contained if battery powered and the alert was wireless. It might also generate a text/audio message if it had access to a telephone connection.

10.2. Hazardous Stove Mitigation:

This device would automatically turn down the heat on a stove heating element that had inadvertently been left on "high" and forgotten.

The device would be designed as an add-on to be inserted in the heating element circuit between the existing controls and the electric burner. It would use time and/or a heat sensor to determine when a burner had been left on "high" too long, and was now getting too hot.

This often occurs when no pot is on the burner, or the contents of the pot have evaporated. The temperature will get very hot, to the point of melting the pot and/or igniting the contents. When an unsafe condition occurs, the device would limit the current, effectively turning down the heat on the burner.

This would be especially valuable in homes with seniors living alone, but useful in most homes. A similar device might be created for gas stoves, but would require external power and gas-tight controls.

10.3. 360 Degree Car Surveillance:

This idea is to protect the vehicle on all sides from collision.

Cameras would be positioned to provide 360 degrees of surveillance. When an object came within range and appeared to be approaching, it would cause a warning/alert so that the driver/owner could do something to mitigate damage.

10.4. Automatic Plant Caretaker:

An advanced system to care for plants when left unattended for lengthy periods of time.

Rather than rely on a passive system that delivered a relatively constant low level of water, a moisture detector would be used to sense soil moisture and deliver an appropriate amount of water. This could also be managed by time and light level, to provide the water at the optimum time. It might also be enhanced with sensors to detect heat and humidity, and add a mister and/or pot rotator.

Though intended to use when the owner is away, it might also be used for routine maintenance.

10.5. Facial Recognition Security System:

A secure entrance would use facial recognition to admit authorized persons.

The entrance would have a camera and a database containing images of authorized persons. When someone arrived at the entrance, they would stand in front of the camera to be scanned. The system would then compare key features in the image to determine if the person was authorized. If so, it would automatically unlock the entrance.

10.6. Parking lot management:

Create a device similar to the Sunpass or EZpass that someone like UCF could use to manage parking privileges in their parking lots and garages.

Instead of a sticker, each parking permit would actually be a transponder that has the driver/vehicle information. When the driver enters the parking area, the driver will receive a text message instructing them where to park, within a time limit (like 5 minutes). If they didn't park in the designated parking spot, the system would assign the parking spot to someone else, and if someone else parked in an area that was not given to them by the network, they would get a violation ticket.

This would provide additional convenience for the driver by telling them where the open space is, and save UCF money by eliminating the need to patrol the parking lot. Additionally, the transponder could be updated electronically to extend the dates rather than issuing new parking permits, also saving resources.

10.7. Remote entrance security system:

Whereas many apartments and large offices have a system of wired doorbells, intercoms, and electrically controlled door locks, we would create a wireless system using WiFi.

These days, nearly everyone has a smartphone. The doorbell at the entrance would notify the resident of a visitor by sending a text message that included an generated image of a QRC code. If they wished to admit the visitor, they would forward the generated image to the visitor. The visitor would then hold up the image to a scanner on the doorbell that read the image and confirmed that it matched the QRC code it had generated and unlocked the entrance door.

The table below summarizes the pros and cons of the project ideas. The green background indicates something considered positive, while red indicates a negative. Based on these assessments, we chose the automatic plant caretaker for having the most positives and fewest negatives.

	Motivation	Feasibility	Appropriateness	Risk	Cost
Delivery Alert System	Increasing use of online shopping and home delivery.	Can stand alone without connection to power and communications	Combines electronics for detection, software, and communicaitons.	Might be difficult to make certain a package was left in the right area.	Low for electric eye, micro computer, and alert
Hazardous Stove Mitigation	High risk of damage by forgetful people	Hazardous working with high power in hot environment.	Combines electronics for detection and control, software to implement logic.	Would require a connection to a high power circuit in a hot location	Costly for High power components and difficult to test
360 Degree Car Surveillance	Costly car repairs reulting from collision damage	Unclear how to mount on car. Competing with car manufacturers	Combines electronics for cameras and display, plus software	Not certain what a person could do even if the hazard were detectred	Moderate for cameras, micro computer, and alert
Automatic Plant Caretaker	Common problem for people on vacation	Competing with passive systems that rarely work well	Combines electronics for detection and control, software to implement logic.	Passive systems exist but require guessing needs in advance	Low for moisture sensor, micro computer, and water control
Facial Recognition Security System	A convenience for people needing secure admittance	Facial recognition software is commercially available	Combines electronics for cameras and lock, plus software processing	Changes in appearance would render system inoperative	Moderate for cameras, micro computer, and lock
Parking Lot Management	Helpful for drivers and security in busy parking lots	System relies on communication with driver on phones that shouldn't be used	Combines electronics for cameras, plus software for logic and communications	System could not prevent drivers from parking in wrong spaces.	Moderate for cameras, micro computer, and transmitter
Remote Entrance Security System	Replaced expensive wired systems	Most people have smartphones and can send images	Combines electronics for cameras, plus software for logic and communications	If someone doesn't have a phone, they must go in person	Moderate for scanner and micro computer and lock

11. Hardware Component Evaluation

11.1. Microcontroller

The Microcontroller is the brain of this project. It controls all of the components of this project. The primary function of a microcontroller is to receive, process information, and produce the desired output. A microcontroller has built-in I/O (input/output) capabilities.

It can read, process and write analog as well as digital data. The microcontroller required a small amount of power to run and stored its programs in EPROM which is a non-volatile memory.

The Microcontroller needed for this project must be able to receive information on both the Wi-Fi Module and the Bluetooth Module from the UV lamp, pump, LDR and the PH sensor. The MCU based on the information received from the PH sensor must also be able to send a high frequency PWM signal to the pump for controlling its speed and the UV lamp for controlling its brightness and intensity, to produce the desired environment for the growth of plants indoors.

All of the components in this project along the Microcontroller serves as a feedback control system to regulate the environment for the growth of plants. For fulfilling all of the mentioned requirements, a low cost MCU with a large number of digital and analog pins, along with a high processing speed and capable of producing such desired outputs within the available budget is needed. The microcontrollers that we considered for this project are the ATMEL ATmega328 and the ATmega168.

The microcontroller is being used for the different circuits in which digital and another circuit will have come for use for the different purpose. There are different systems in which the buses are connected as well. The different bus systems are present to perform the different functions in such a circuit.

The digital and others are attached in the arrayal form to perform the different functions of the system. The system is designed in the different parallel buses system. The different digital systems like ROM in the PC control the bus system to transfer the data from one to another side to perform the proper function in this case as well. The following picture is given

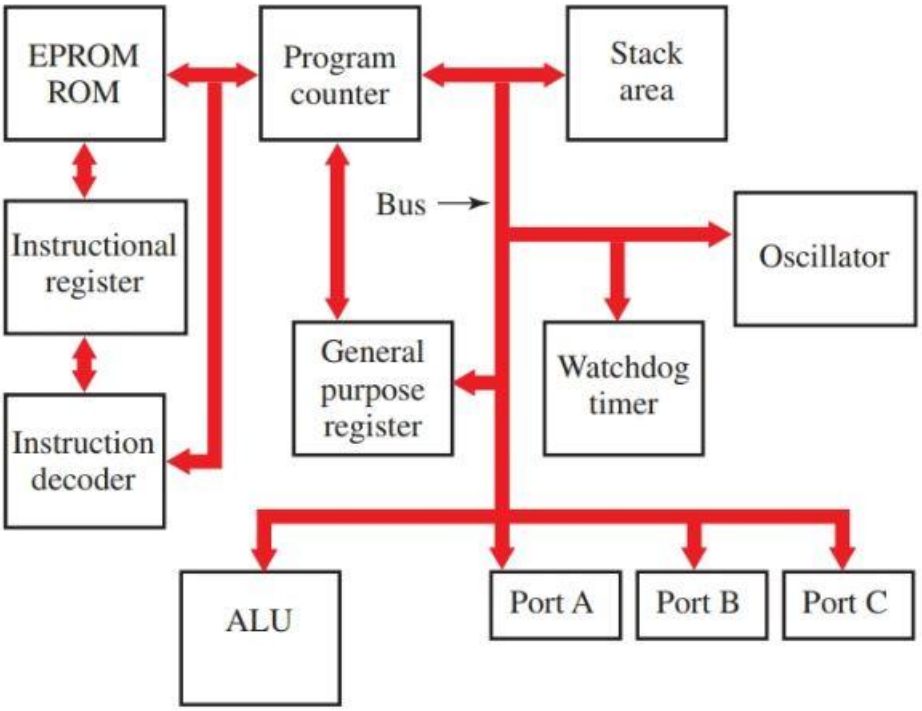


Figure 4: "Microcontroller Function"

In this system, different buses system is attached to perform the work on the rom of PC like instructional register instructed to pass into ROM processor then go toward the programmer and then a general-purpose register as well. Different port A, port B, port C are attached and give ALU as well. The digital system gave the different networks for work in the sequences.

They all are attached to perform their work in a parallel and sequential manner. Some pins are attached in the sequences of output and input side of manner and to perform their work very well in this case. If you change the direction of the pin from input to output it will be difficult to perform in the exact direction.

The digital work can be done if the pin direct will be exactly what it is in placed.

For Example, if we manipulate the data of mathematical form it will perform in a different direction like in this picture which is drawn below if the analogic is equal then the result will be different.

Like the alarm is set differently if the one register A is equal to the register B then the alarm set will be different like it is closed in the set. When we compare the two registers either they are A or B and B or C . If they are equal then the set of running alarms will be closed as well.

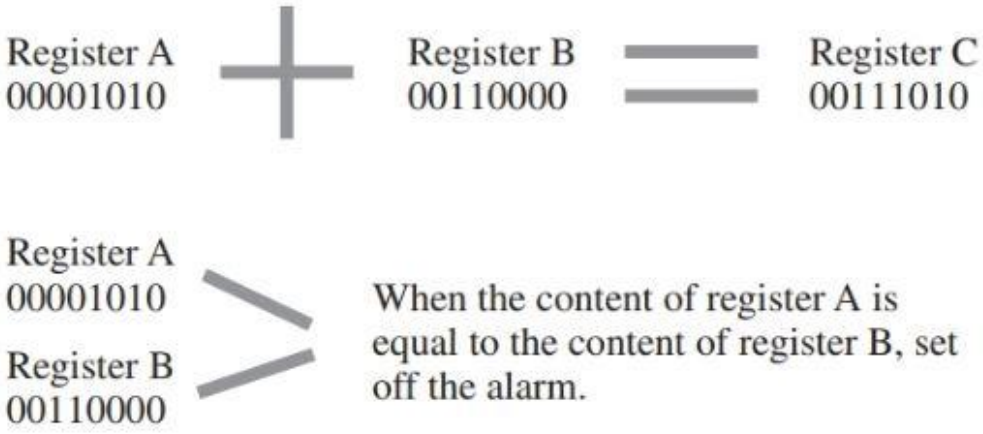


Figure 5: "Registers Function"

11.1.1. Program Counter and Stack pointer

The special device is called the stack pointer which is related to stacking the direction when the on processor finished the work they command to do the next to avoid the interruption in this case. IF face any kind of interruption the system will be stopped and the system will be disturbed as well.

So all the system is created to perform the different direction and to make the work completed on such kind of bases and to perform the exact and great function in this case. When the processor is free it gives the command to perform other functions. They altogether don't perform the equal function to the disruption that will occur.

As the stack pointer gave the direction program counter does the work in that same kind of way. As the given figure below

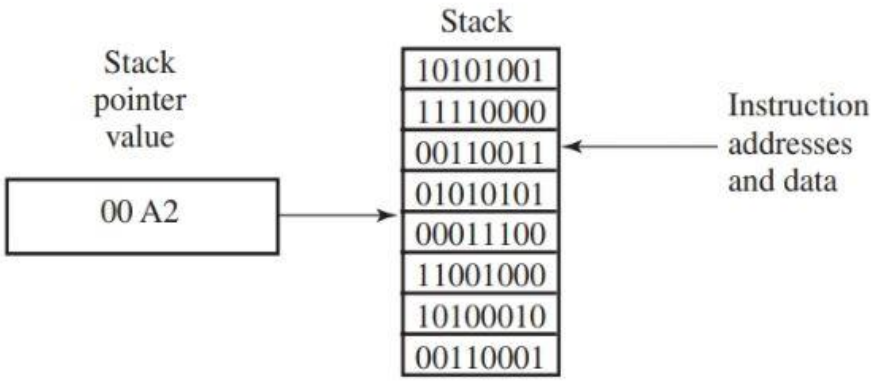


Figure 6: "Register"

The stack pointer is used to do the memory location keeping track of the signal in the sequence and it's referred to stack, then manipulate the data and check the different interruptions. The interrupts are two types Hardware and software interrupt.

Hardware interrupts are those in which input 3 numbers are used for receiving the signals from the button that is pushed and other than the microprocessor is responsible for the signal detector.The stack pointer is always located on the latest bookmark When the interrupt service is finished by the processor.

They popped the counter address and returned to the counter program. The instruction order given by the microprocessor is the same as the direction is given in it. The program counter and stack pointer work in that direction in which the work will be performing in the good and exact way what they want to do. The processing will be going in the right direction and the hardware and software also work good as they want to get direction from the interrupter

11.1.2. ATMEL ATmega328:

The ATMEL ATmega328 is an easy to program 8-bit Microcontroller and is a popular choice for most projects, since it provides a user friendly interface. It is a 28-pin chip with an operating voltage ranging from 1.8V to 5.5V and with a 2KB SRAM along with a 32KB flash memory.

It has 13 digital I/O pins with 6 analog I/O pins and 1KB of Electrically Erasable Programmable Read Only Memory(EEPROM). The EEPROM allows it to store data and in case of shut down can provide results after electrical power is provided to it

Arduino and runs on a 16Mhz crystal oscillator. On AliExpress 10 pieces of ATmega328 cost around US $16. 8. This Microcontroller can be easily programmed using the Arduino IDE environment.The ATMega-328 is that in which different specifications are described to perform the system very well. It has the different valuable description about that for which purpose it is used and who it is used necessarily the following description are given below

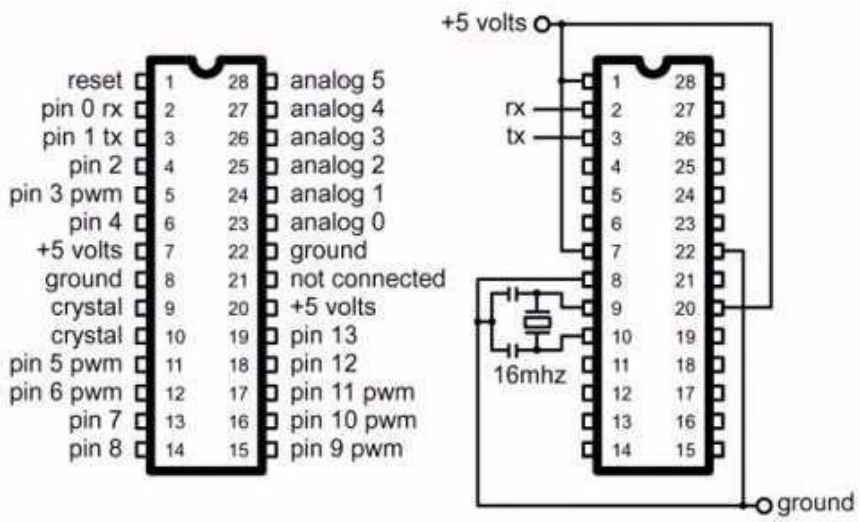


Figure 7: "ATMega328"

- It is specially designed for the higher-performances by microchip. It is an 8-bit microchip that is used for the main purpose.
- It combines with 32 flash memory for reading-writing purposes. It performs well and is controlled all over the system.
- Its 1Kb EEPROM and 2KB SRAM microsystem for quality work.
- It has compared mode with compare 3 flexible other modes like compare mode, external mode and last one internal interrupted.
- The device operates between 1.8 to 5.5 volts
- The serial interface which is a two-wire system port is SPI serial, channel that is 8-channel system QF packages and TQFP also and others are 6-channel converter with 10 bits.
- They are powerful chips that control all over the system exactly the main way to perform well and to do a good performance.
- It also balances the processing speed and power that will be balanced as well. By the single clock cycle with the execution of strong instruction by approaching the MIPS per MHz as well.

Figure 8: "ATMega328"

The processor of the microchip performance is very good. It's a micro but qualities are the excessively high performance to do all over the function in the exact system. It combines with 32 flash memory for reading-writing purposes. It performs well and is controlled all over the system. It has good processing speed and powering balancing system as well. It has a different bits system to perform the great and good quality of work throughout the system. The main thing is its combine with 32 flash memory for reading-writing purposes. It performs well and is controlled all over the system. The microcontroller is the best for performing different and purposive work. It can give the different and good performers and to go throughout the system. So the performance of the microchip at mega is quality-based. It can process all the work with the best specification

11.1.3. ATMEL ATmega168:

The second choice for a microcontroller is the 8-bit ATmega168 Microcontroller. It is the predecessor of ATmega328 with 16KB of flash memory, 1KB of SRAM and 512 bytes of EEPROM. Its operating voltage ranges from 2.7 to 5.5V. Its price is generally low ranging from $1.2 to $1.3 per piece. It is easily programmable using the Arduino IDE and works on a 16MHz Crystal oscillator.

It's an AVR microcontroller that is 8-bit having a 32-pin interface. It is based on different technology like CMOS and Is. The programmer has 16K memory that can control the reading

and writing chip that accesses for the different programmers.

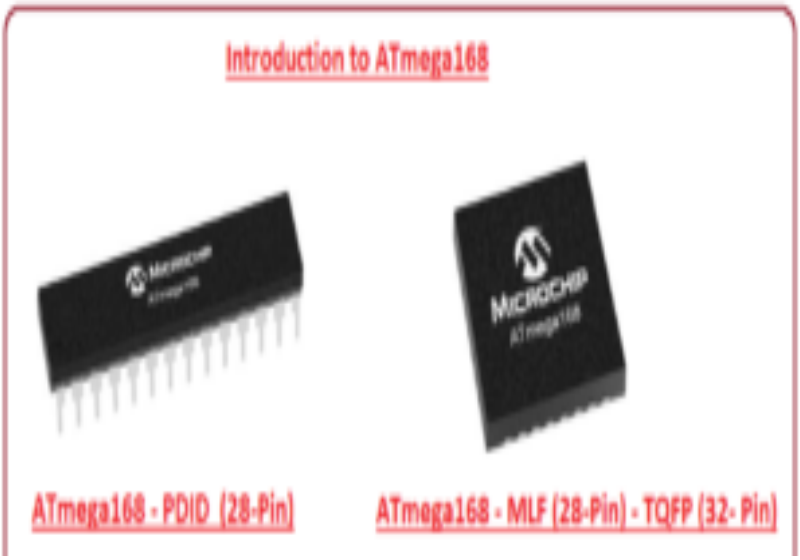


Figure 9: ATMega168

The temperature is in the different wide time that is 1.8 to 5.5 V project that is related to the embedded system or other like automation than the project never ignores the importance of this structural module system that we are using in it. It comes with different abilities to be used n=by different programming systems and utilized in a good manner as well. It is that in which the different function that is used in the one performer has been embedded in the single-chip system all things will be happening by it. Now the feature and all over the module system will be given in the different points it will clear how the chip used for performing the different function easily in this following case. It is the real application system in which different processors are used to perform the work and has been happening in the good but exact the different and good manner to perform all the situations that are present. The chip in itself is the great system in which all the things are present to perform good and to keep in self exactly the good and the hardcover is for protecting it.

11.1.4. ATMega Characteristics

- It's an 8-bit micro-controller with different AVR controllers and it has come in different packages systems like TQFP, MLF, PDIP .They have 32-pins in the interface and 28 on each side of the module system.
- The memory program is about 16K that consists of the Flash-based system and the other will be the EEPROM and the RAM system of 512 and 1K accordingly. The around the 20-year data retention capability is present.

- The ADC system module is the 10-bit initial system that comes into the device system and plays a great and vital role in the interfaced sensor detection and also contains a channel that is a total of 8 that gives the digital conversion into the consistency of pin because it is a digital conversions system in such a case.
- Some are responsible for the different communication system protocol that is 12C, SPI USART and AT mega is one of the best in them. All the protocol has been followed and used for the communication attached with different external devices
- This device worked very well and efficiently in such a case and performed the good and very great valuable manner as well. The chip contains all the information that is used in the digital system as well.

11.1.5. MSP430G2553:

The third choice for a microcontroller is the MSP430G2553. This microcontroller costs around 10$, runs at 16MHz with 16KB of flash and an input voltage 5V. This Microcontroller needs more coding to properly use an LCD, take in analog inputs, and for the initial setup than the Arduino, and also it is not supported for Mac or Linux environments. Also, It contains 0.5KB of RAM.

The key features of MSP430G2553 are: It can be used for the removal of MCU with high quality with 20 pins DIP socket, it can support MSP430G2xx1, MSP430G2xx2, MSP430G2xx3, and MSP430F2xxMCUs in PDIP14 or PDIP20 packages. For ultra low power debugging this module can be used. For user interactions, it has 1 button and three LEDs

The ATmega162 is also manufactured by the same company ATMEL.

11.1.6. Microprocessor Comparison:

In comparison of the features of different Microcontrollers present in Table 4 the need for a competent microcontroller in this project are met with the ATmega328 Microcontroller. The reason is that the MSP430G2554 Microcontroller has too many features that are not necessary for this project. One reason is that in this project no analog outputs are to be sent to any part of the board.

Also the ATmega328 has a higher processing speed 20MHz compared to the MSP430G2553. Since some important components of this project are to be run at higher voltages(12V), keeping this in mind, the ATmega328 is chosen because it can be run at higher voltages.

Comparing the ATmega328 and the ATmega168 Microcontroller the processing speed of the ATmega328 is higher compared to the ATmega168 Microcontroller. Also the ATmega-328 contains higher flash Memory (32KB), EEPROM (1KB) and SRAM(2KB) compared to both the ATmega168 and the MSP430G2553 Microcontroller.

This allows it to perform better than the mentioned microcontrollers. Also the price of the ATmega328 is quite reasonable although it is more than the ATmega168 Microcontroller.

Table 4:. Comparison of Microcontrollers

Feature	ATmega328	ATmega168	MSP430G2553
Operating Voltage	$1.8 - 5.5V$	$2.7 - 5.5V$	$1.8 - 3.6\ V$
Temperature Range	$-40\ to\ 85℃$	$-40\ to\ 85℃$	$-40\ to\ 80℃$
Max Clock Frequency	$20MHz$	$16MHz$	$16MHz$
Memory	32KB Flash, 1KB EEPROM, 2KB SRAM	16KB Flash,512B EEPROM,1K SRAM	$16\ KB\ Flash$ $0.5SRAM$
Analog I/O	Input only	Input Only	Both
Digital I/O	Both	Both	Both
GPIO Pin Count	23	23	24
Bit count	8-bit	8-bit	16-bit
Low Power	Yes	Yes	Yes
Power Consumption	Active Mode: $200\mu A@1MHz$ Off Mode: $0.1\mu A$	Active Mode: $1.8mA\ and\ 3V\ @4MHz$ Off Mode: $5\mu A\ at\ 3V$	Active Mode: $330\mu A@1MHz$ Off Mode: $0.1\mu A$
Price	$\$16.8/10pcs$	$\$1.2\ to\ \$1.3/pc$	$\$19.83/10pcs$

11.2. Arduino IDE

Arduino IDE is Open Source Software. Make it easy to Write, Compile and Verify and Upload the code to the Microcontroller. These software have some features like this IDE is easily

available for Windows, comes with inbuilt functions ,commands that play a very important role for debugging ,compiling and uploading.

Support a lot of Boards. Code or Sketch created on the Arduino ide platform generates a .HEX file which is transferred and uploaded in Microcontroller. Arduino IDE supports C, C++ languages.

The Arduino integrated development environment is the best application like cross-platform for example Linux, Windows, macOS, etc., that is used for writing the language in the form of C and C++. It is specially used for programming upload purposes and also writing purposes too with help of core that is a third party for other board development vendors as well.

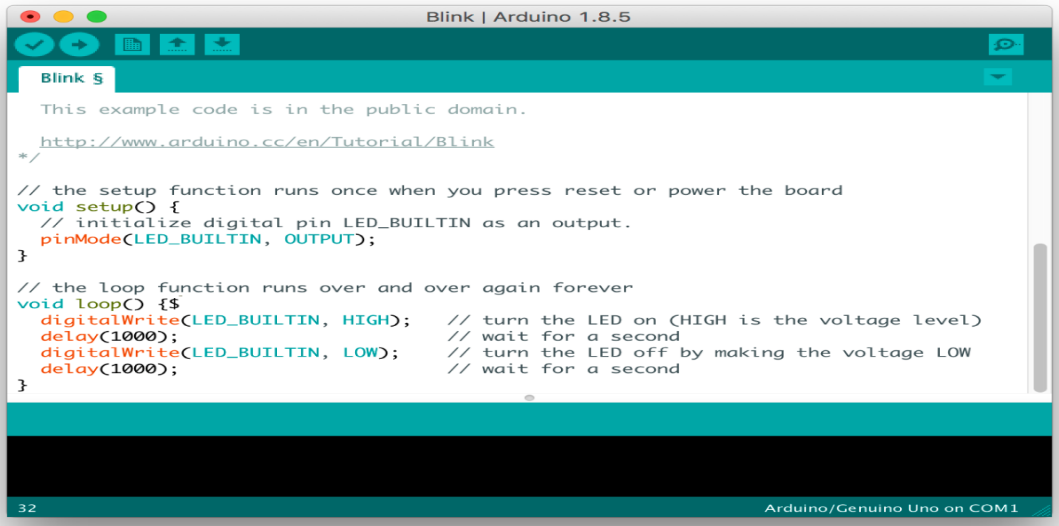


Figure 10: "Arduino IDE"

The different code that is source-based IDE and other will be GNU licenses that are released that are version 2 as well. There are different language systems that as C++ and other C languages by using different structure code systems as well.

The Arduino IDE is used for wiring projects too on the software library as well. Many others are using this for different language systems in this case, it can be used by the different input and output system and design the different manner as well by using the application.

The different writing codes are just in the two-way processing. For the main program, the sketch is done starting. in this compiling and programming linked with other GNU tools.

The Arduino IDE employees like the avrdude programming and then convert all the code into another file as well. So hexadecimal coding like the firmware board as well. Arduino board's official used the code and uploading tool to flash by user code in avrdude.

Arduino IDE is the processing IDE and the version is 2.0 by Eclipse Theia and Visual Studio Code as well.

11.3. Bluetooth Module:

The Purpose of a Bluetooth Module is to communicate with the Microcontroller. It transmits and receives information from the different modules such as the soil moisture sensor, LDR and the PH sensor through the Microcontroller and displays it on a Bluetooth app on a smartphone. There are many variants of the Bluetooth module available in the market which are the HC-05, the HC-06 modules and the BLE link Bee and many others.

For the communication system. The wireless technology of the communication that is Bluetooth device system is introduced for the main communication system also for transfer of main files from one to another one device. It's the latest technology system that is used everywhere here like in the cellular as well. In communicating with them.

It is a very popular and fastest technology that is spreading in the world now every device is using is perfect as well and doing best with Bluetooth wireless system. In communication devices the best system is quite easy; it can be processed differently as well.

The Bluetooth technology is the best in communication and other purposes and it is the wireless part which is the best in the case. It can be used in different devices as well for the communication system. The Bluetooth can be used for the best controller processor like when we communicate with others it will transmit the data in the air and signal will be detected in the waves form and communication will be made easy.

It can be used as the host-controlled interference system in such a device. The UART and USB are the popular host communicator devices as well. By using the UART connections, Bluetooth is the best for every communication system in the case as well. It can be detected by the waves and change into the signal.HC 05 Bluetooth is the best communication protocol system as a wireless system that is receiving and sending the information and another wireless system is Wi-Fi and ZigBee. The frequency is 2.41 GHz.

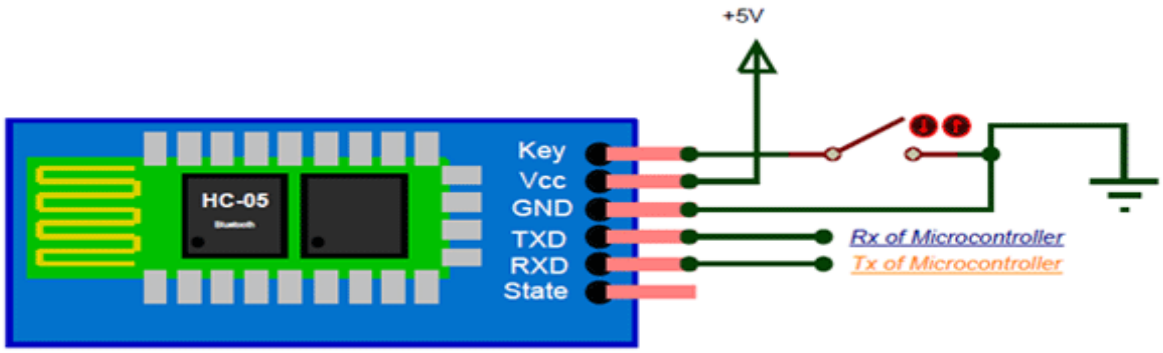


Figure 11: "Bluetooth Module"

Bluetooth Module classification are following
The following classes are given as

Class 1: Class 1 of Bluetooth is about 100mW and the distance between the 2 different Bluetooth is about 100 meters.

Class 2: The other class is a different output range device is about 2.5 mW and has a distance of 10 meters.

Class 3: This output range is about 1mW and the distance is 10cm between two Bluetooth devices.

11.3.1. Bluetooth Module Comparison:

Comparing the three modules HC-05, HC-06 and the BLE Link Bee module whose features are given Table 5, the HC-05 module has been chosen to be the Bluetooth module that is to be used in this project. Comparing the HC-05 and the HC-06 module the only difference between them is that the HC-05 can work both as a slave and a master while the HC-06 can work only as a slave device. Both have the same price, their transmission range is 9m and their working voltage is 3.3V.

The BLE Link Bee has higher transmission range i.e., 60m compared to the HC-05 and the HC-06 modules but its speed is less i.e., 1Mbps. The reason for not choosing the BLE Link Bee Module is that its price is large compared to the HC-05 and HC-06 modules and most of the work in this project can be accomplished using the HC-05 Bluetooth module.

Table 5: Comparison of Different Bluetooth Modules

Feature	HC-05[2]	HC-06[1]	BLE Link Bee
Transmission Range	$9m$	$9m$	$60m$
Voltage Requirement	$3.3V\ DC$@$50mA$	$3.3V$@$40mA$	$3.3V$@$10.6mA$
Frequency	$2.4GHz$	$2.4GHz$	$2.4GHz$
Slave	Yes	Yes	Yes
Master	Yes	No	Yes
Android Compatible	Yes	Yes	Yes
PRICE	$2.22 - 2.7	$2.22 - 2.7	$9.90
Speed	$2.1Mbps$	$2.1Mbps$	$\leq 1Mbps$
Working Temperature	(− 20℃) to 75℃	− 20 to 55℃	− 40 to 85℃
Bluetooth Version	2.0	2.0	4.0

11.4. Soil Moisture sensor:

The purpose of the soil moisture sensor in this project is to measure the amount of water/moisture that is present in the soil. This is done to ensure that a necessary amount of water is present in the soil to promote the growth of plants. On the basis of principle of operation there are two types of soil moisture sensors. These are as follows:

- Sensors that measure the resistance of soil:
    - The soil moisture sensor works on the idea of resistance. It passes current through the soil and according to the resistance of the soil to the electrical current measures the moisture level in the soil. Less water results in less conductivity and more water contributes to allowing higher current resulting in less resistance to the flow of current. The soil moisture sensor is an easy to utilize module.
- Sensors that measure the soil capacitance:

- This sensor measures the volumetric content of water inside the soil. It is made of corrosion resisting material which gives it an excellent service life. It measures the moisture content by measuring the change in capacitance. It is made up of two plates; one is positive and the other is negative and between them a dielectric medium. It is also easy to use because it provides an analog voltage signal which can be read using a microcontroller.

- Soil moisture sensor has two parts conducting plates and another one is probe and the variables tighter when the sensor is used in the water inserted into land water will be conductivity and resistance decrease.

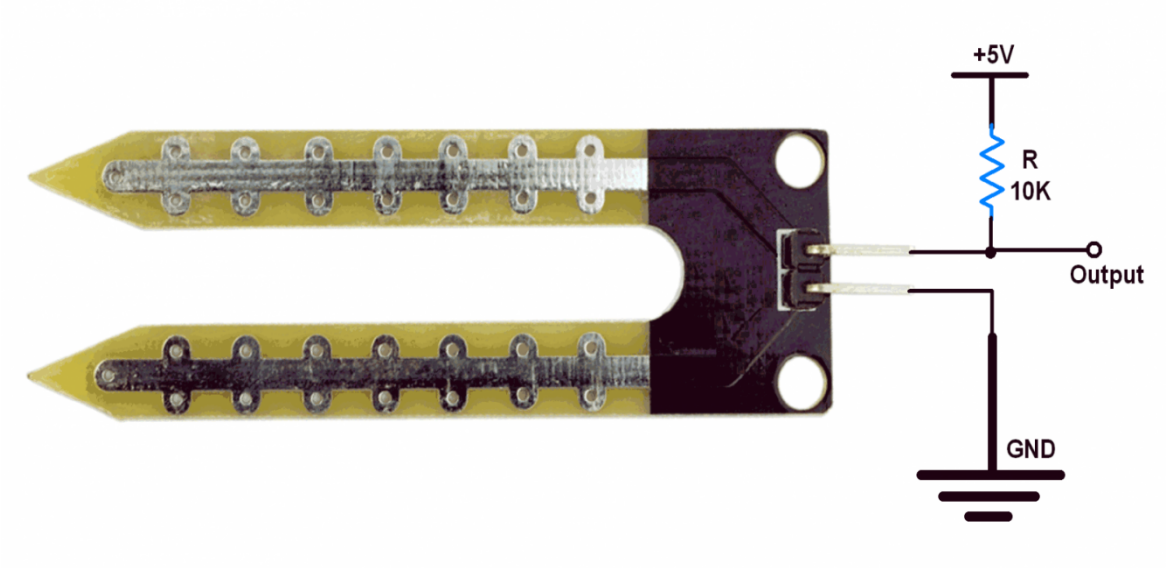


Figure 12: "Soil Moisture Sensor"

The figure shows the soil moisture of the working principle of that sensor.

- It has two types of conducting plate one is about to be connected to the +5Volt supply through series resistance of 10K ohm and the other will be directed toward the ground system.
- It has a network of voltage divider biased system as well and the output is directly connected to the one terminal present on the first as shown in the above-given figure
- 0 – 5 Vol output will change when the water in the soil will proportionally change in it.
- If we consider there is zero moisture in the soil and if the circuit is open .The infinite resistance will happen like 5V at the output one.

- Soil sensor is the best for the water detection from the land it will use for the best convince purpose
- Many people are using these modules in their project work to detector the water in the soil as well.
- Whenever the sensor is used in the water, conductivity increases and resistance decreases.

  So it is used in the projects as well for another type of production which will happen to do in such cases

11.4.1. Moisture Sensor Comparison:

Table 6 compares the features of the resistive and the capacitive soil moisture sensors. Both the sensors have nearly the same electrical requirements and their price is also comparable and low.

Keeping in view the effect of corrosion on equipment, the capacitive type of soil moisture sensor is selected for this project because the resistive soil moisture sensor does not have protection against corrosion.

Table 6: Comparison of Resistive and Capacitive Soil Moisture sensors

Feature	Resistive[4]	Capacitive[4]
Input Voltage	$3.3 - 5.5V\ DC$	$3.3 - 5.5V\ DC$
Output Voltage	$0 - 5V$	$0 - 3.0V\ DC$
Input current	$15mA$	$5mA$
Price	$0.74[3]	$0.63 [3]

11.5. Single Channel 5V Relay

Using an electric current, a relay opens or closes contacts on a switch. Use it to operate a switch. It is used to control the operation of a toggle switch, as its name suggests. These components make switching and connecting easier even though they look like a simple relay. A power-on indicator and a relay-operation indicator are also included.

It contains components that make switching and connecting easier, as well as indicators that indicate whether or not the module is powered on and whether or not the relay is active.
The terminal block of the screw is the first thing that needs to be examined. Because this is the portion of the module that comes into direct contact with the power supply, a solid connection can be guaranteed. Screw terminals, which have recently been introduced, make it easier to connect thick power cables, which can be difficult to solder directly, than it was previously. Each of the three terminal connections on the terminal block is connected to one of the three relay terminals, which can be configured to be normally open, normally closed, or common depending on the situation at the time of installation.
The second component is the relay itself, which is represented by a blue plastic case in this instance. The markings on the relay itself contain a wealth of information that can be gleaned from them. In the bottom-right corner, you'll see the part number "05VDC," which indicates that the relay coil is activated when a voltage of at least 5V is applied to it; any voltage lower than this will not reliably close the relay contacts. Other markings are available, including voltage and current markings, which represent the maximum voltage and current that can be applied to the relay without causing it to malfunction. The top left mark indicates "10A 250VAC," which indicates that when the relay is connected to a 250V power circuit, it has the capability of switching a maximum load of 10A. In this case, "10A 30VDC" is written on the left bottom of the relay, indicating that the relay can change a maximum of 10A DC current before the contacts become damaged.
It is possible to tell how much current is flowing through the relay spindle when the relay is activated by the LED "relay status," which illuminates when it is turned on.
This circuit's input jumper is in charge of supplying power to the relay coil and LEDs on the other side of the circuit. The jumper also has an input pin that, when pulled high, activates the relay, and a ground pin for connecting to the grounding system. For the purpose of driving the relay belt, the switching transistor takes an input signal that does not provide enough electrical current to directly drive the relay belt and amplifies it by utilising the delivery voltage to accomplish this. Therefore, it is possible to directly drive the input from a microcontroller or sensor output. When the relay is turned off, the freewheeling diode prevents voltage spikes from forming in the circuit, which would otherwise occur.
As soon as the module is powered up, the power LED connects to the VCC and illuminates, indicating that the module has been powered up successfully.
The relay operates by utilising an electric current to open or close the contacts of a switch, similar to how a light switch operates. If the spiral has not yet been activated, this is typically accomplished through the use of a spring that pushes the contacts apart if they have not yet been attracted and joined together by the switch's contacts.
Using this system has two distinct advantages: first, it saves time. Starting with the energy required to activate the relay being significantly lower than the current, switchability of the relay

contacts results; second, the coil and contacts are galvanically isolated from one another, resulting in the switchability of the relay contacts. Because of this, the relay can switch power through an insulated low-voltage digital system, such as a microcontroller, without causing damage to the system.

11.6. ULN2003

The ULN2003 integrated circuit is one of the most widely used IC engine drivers currently available on the market. In digital logic circuits such as op-maps, timers, gates, the Arduino, the PIC, and the ARM, among others, this integrated circuit is useful for driving high current loads, which makes it an excellent choice for driving high current loads. If, for example, the Arduino I/O cannot supply enough current and voltage to power a 9V and 300mA powering engine, we must use this IC to provide enough current and voltage to power the engine, as shown in the following example. This IC is commonly used to drive relay modules, motors, modern LEDs, and even stepper motors, to name a few applications. For anything that requires more than 5V 80mA, this is the most appropriate integrated circuit for you to use.

The ULN2003 is a 16-pin integrated circuit with a programmable logic controller. There are seven Darlington Pairs in each module, and they can be used to drive charges of up to 50V and 500mA at a time with one module. It is possible to connect up to seven input and output pins for each of the seven Darlington pairs. If we so choose, we can also have a soil and a common pin. Traditionally, the ground pin serves to ground the circuit, and the use of the common pin is entirely optional. On this integrated circuit, it is noteworthy that there is no Vcc (power) pin. This pin is required because it is responsible for drawing the power required by the transistors in order for them to operate. The circuit shown below is a simple design that can be used to test the functionality of the ULN2003 integrated circuit. It is intended for use in educational settings.

Loads are defined as LEDs in the circuit, and logical pins (blue in colour) are defined as pins that connect to the digital circuit or to microcontrollers such as the Arduino, respectively. Please keep in mind that the positive pin of the LED is connected to the positive load voltage, while the negative pin is connected to the IC output pin of the LED. This is critical information. Due to the fact that when the input pin of the IC is high, the corresponding output pin of the IC is connected to the floor, this is what happens: It is as a result of this that the circuit is complete and the LED begins to glow when the negative LED terminal is grounded (see Figure 13). It is possible for the output pin loads to be as high as 50C and 500mA for each of the four output pins on the device. It is possible to purchase higher current loads, on the other hand, by connecting two or more output pins together in order to collect current. In order to drive up to (3*500mA) 1.5A with three pins, you must combine them. This is a significant amount of current.

A switch can be used to connect the COM pin to the ground, allowing it to function properly when not in use. Alternatively, a test switch can be used, which means that if this pin is grounded, then all of the output pins are grounded as well.

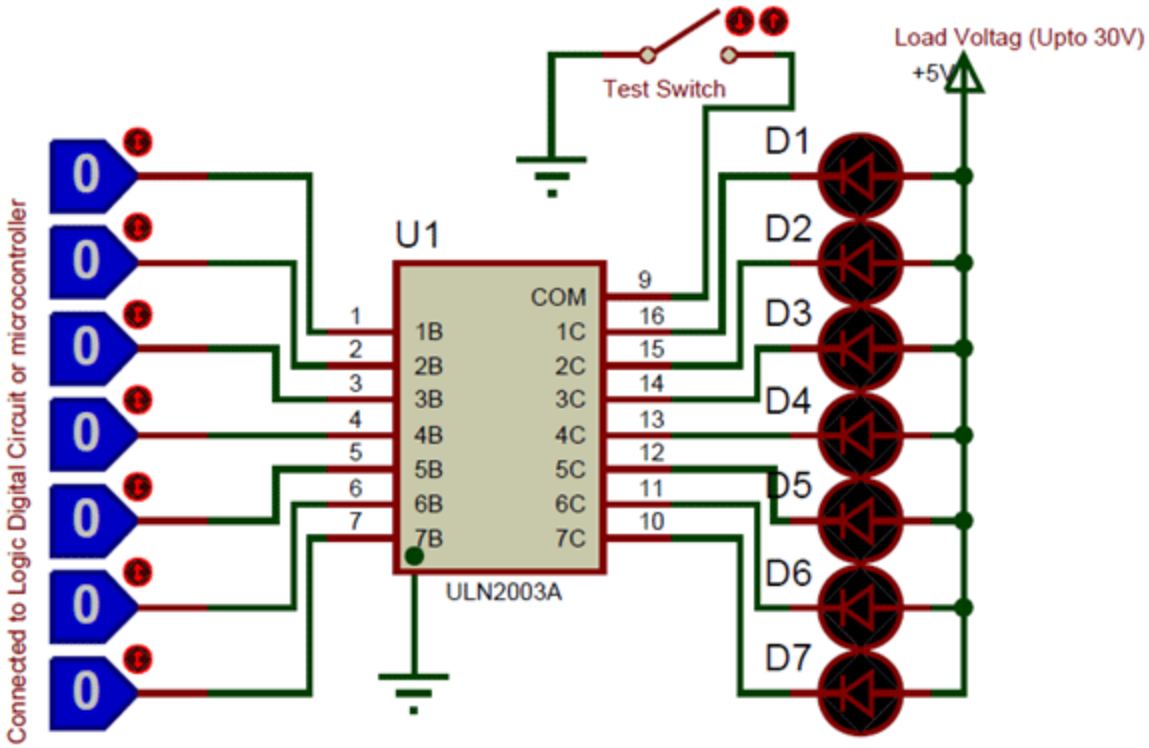


Figure 13: "ULN2003 Pin configuration"

11.7. BUCK Converter (LM2596)

Direct Current to Direct Current Converter (also known as DC-DC Buck Converter) is an acronym that stands for Direct Current to Direct Current Converter. With excellent line and load regulation, the Power Supply drives a 3-amp load while maintaining a low power consumption. For these devices, output voltages of 3.3 V, 5 V, and 12 V are available, as well as adjustable output voltages for these voltages.

With a switching frequency of 150kHz, the series LM2596 switching regulators are able to use smaller filter components than switching regulators with lower switching frequencies, allowing them to be more compact.

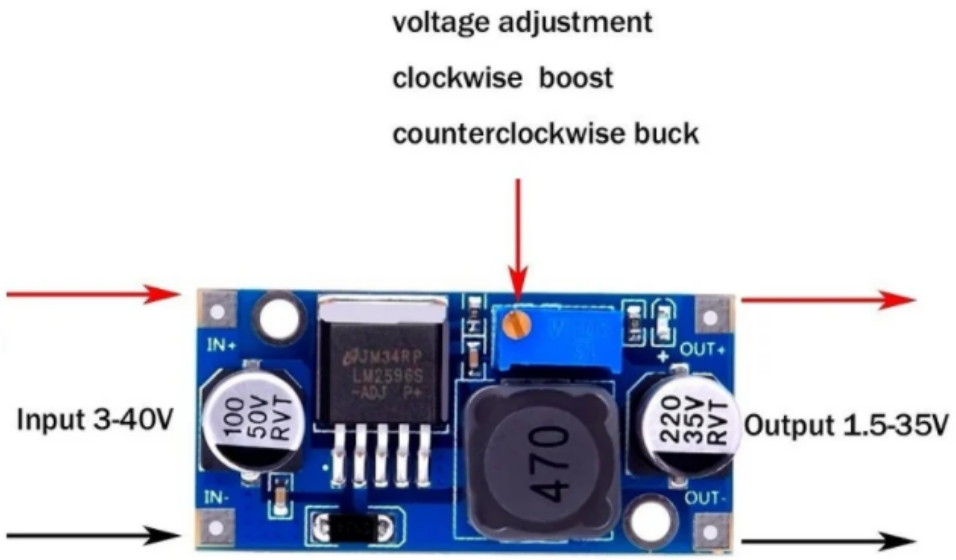


Figure 14: "BUCK Converter (LM2596)"

Arduino UNO, other mainboards and basic modules are used in this project. The buck converter and high precision potentiometer used in this project are from the LM2596 and can drive a load of up to 3A while maintaining high efficiency. The device should be equipped with a heat sink if the output current is greater than 2.5A (or the output power is greater than 10W).
Due to the fact that this device is internally compensated, the number of external components and the complexity of the power supply design can be reduced significantly.
In part due to the fact that it is a switch-mode power supply, the LM2596 is significantly more efficient than popular three-terminal linear controllers, and it is capable of handling extremely high input voltages without sacrificing efficiency. It is possible to use smaller filter components with the LM2596 because of its high switching frequency of 150 kHz, compared to the larger filter components required by regulators operating at lower switching frequencies.

11.8. Wi-Fi Module:

There are two data transfer modules in this project. The primary is the Wi-Fi Module and the secondary option is the Bluetooth module which is to be used in case no internet connection is present or in case of failure of Wi-Fi module. The Wi-Fi module helps in transferring data from the Microcontroller and displays it on the smartphone app. There are a number of Wi-Fi modules available in the markets which include the ESP-01, and the ESP-05.

The Wi-Fi Module is a very important component of the microcontroller if we are sending or receiving data through Wi-Fi. This module is worked as a host between the microcontroller and Wi-Fi network Pre-programmed with ESP8266 module are set with the set fire ware like you used the WIFI device with the Arduino device and get best ability to do work in the

effective board of extremely cost as well and have huge and community.

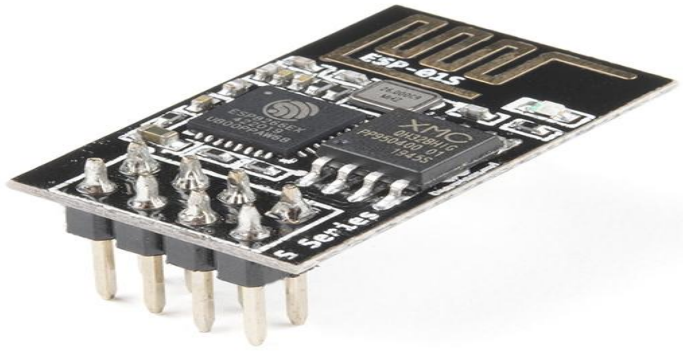


Figure 15: "WiFi Module"

This Wifi module has the capacity to store many items as powerful storage and the capacity to connect other devices for sending and receiving data. A large number of fountains of information for the module ESP8266 are available, all of these fountains delivered by a supporting community.

11.8.1. WiFi Module Comparison:

The ESP-01 is probably the most popular Wi-Fi Module. It is also compatible with Arduino and easy to program. Comparing ESP-01 to the ESP-05 both modules have the same features but the ESP-01 has 2 general purpose input/output pins while the ESP-05 has none.

Both the modules cost the same. While the ESP-01 does have the advantage of being compact, for this project the ESP-01 is to be used, due to our familiarization with this module.

Table 7: Comparison of Wi-Fi Modules

Feature	ESP-01	ESP-05
GPIO Pins	2	0
ADC	No	No
Antenna	PCB	PCB
Breadboard friendly	Medium	Good

Price	$3	$3
Voltage	3.3V	3.3V

11.9. PH sensor:

If we want to measure the acidity or alkalinity of any substance then we use a PH sensor for this purpose. The scale for PH measurement is 0 to 14. The negative algorithm of the hydrogen ion (–log10 [H+]) is known as PH, it is the formal and mathematical definition of PH.

In the practical field acidity is the hydrogen ion activity which we have to measure. How we can use pH value and how it can be measured in a well sequence .PH is the best measuring tool that is potentiometric. It is always used to convert the signal that is electrical into reading PH.

The potential difference has measured the difference between reference electrodes and sensing. The Ph slope has 7 is 0mV and the other will give ~59 mV in the line. This means PH will be changed in every manner.

The potential activity and hydrogen ion relationship will be explained by the Nernst equation:

$$E = E_0 - 2.3\left(\frac{RT}{nF}\right) log\ a_{H+}$$

Where:

E = “total potential (in mV) developed between the sensing and reference electrodes”

E_o = electrode standard potential is” a_{H+} = 1 mol/L
R = constant of Gas
T = temperature
n = Total electron in numbers
F = Faraday constant
a_{H+} = “Hydrogen ion activity in the solution

Figure 16: "PH Sensor"

The term 2.3RT/nF is referred to as the Nernst slope. For an ideal electrode, the slope at 25°C is 59.16 mV per decade change in hydrogen ion activity. In reality, the behavior is slightly different than in theory. Calibrating the sensor compensates for this by determining the actual slope and offset using buffers and updating the data-collection software" accordingly.

Vernier pH "Sensors are combination electrodes. This means the sensor contains both the reference and measuring electrode in one body. When the sensor is placed in the solution, the glass bulb senses the hydrogen ions and the internal electrolyte solution picks up the signal from the glass bulb.

The silver/silver chloride/ (Ag/AgCl) reference electrode containing electrolyte generates a constant potential. The difference between the reference and measuring electrodes is a function of the pH" value of a solution.

The purpose of the PH sensor in this project is to measure the acidity of the soil that is present for the growth of plants. The PH sensor gives a value from 1 to 14. The value of 7 represents neutrality. As the number increases from 1 the alkalinity increases and reaches its maximum at 14.

The pH value is equal to the negative logarithm of the hydrogen ion concentration. There are four types of pH sensors: Combination pH sensor, Differential pH sensor, Laboratory pH sensor and Process pH sensor. The water that is present in the soil has a certain value of pH and the pH sensor measures it.

The combination pH sensor is most widely used, so we will utilize it in this project. There are a number of pH sensors available on amazon and other websites. Two of them that were considered in this project are FBM0-AAQ-13688 from the manufacturer DONGKER and the SEN0169-V2 from the manufacturer DFROBOT. These sensors are specially designed for Atmega328 Microcontroller.

Specifications:

- Input Power: 5V (Power Indicator LED)
- Module Size: 43mm x 32mm
- pH Measuring Range: 0 – 14pH
- Temperature Measuring: 0 to 60 Degrees
- pH Interface: 2.0
- Gain Adjustment: Potentiometer

pH Electrode Characteristics

It is very difficult to find a low-cost PH meter that is being used to measure the water quality and other parameters. Here we used an analog meter that measures the PH scale of the substance and was specially designed for the Arduino controllers if we discussed the building design of the meter which is very simple and practical features and connections. If we discuss the design of the meter, it has a power supply indicator which is an LED, a connector that connects with other devices is BNC and an interface of PH2.0 which senses the PH of the substance. For using this module we have to connect the PH sensor with connector (BNC) and plug in the interface with an analog input of the Arduino controller. For the pre-programmed module, it will get the values very easily. But one thing that should be in mind is to make sure the accuracy of PH value, for this purpose we have to use the standard solution to calibrate it regularly.

Use of a pH Meter

When we have to use the PH meter, we have to use the external power supply for this purpose and the voltage should be near 5.0V. As voltage will be more accurate accuracy will be higher.

If we want to get more accurate results then we have to use electrodes by calibrating it by a standard solution. The temperature that is best for calibration is 25 C and the value of PH will be more reliable.

When we use a PH meter to measure the PH values of different solutions, we have to wash it after using one time to get more accurate results.

1. When we use this PH electrode for the measurement of the PH, we have to connect it according to the procedure mentioned above and connect with the Arduino controller, when the Arduino controller will get power supply then we will see the Led on board is on.

2. Next step is to upload the developed code to the Arduino controller.

3. For the measurement of the PH, we have to put the PH electrode into the required solution to get the results, results will be shown on the display, value of PH will be between 0 and 14, which will determine that the solution is acidic or alkaline.

pH Electrode Characteristics:

Voltage (mV)	**pH Value**	**Voltage (mV)**	**pH Value**
414.12	0.00	-414.12	14.00
354.96	1.00	-354.96	13.00
295.80	2.00	-295.80	12.00
236.64	3.00	-236.64	11.00
177.48	4.00	-177.48	10.00

118.32	5.00	-118.32	9.00
59.16	6.00	-59.16	8.00
0.00	7.00	0.00	7.00

FBM0-AAQ-13688 :

The sensor from the manufacturer DONGKER has a weight of 3.63 ounces and supports the Microcontroller that is used in this project and the ARDUINO IDE environment. Its voltage rating is 0 to 5V and its measuring temperature is from *0 to 60*℃. The response time of this sensor is less than a minute. This sensor also measures temperature. The package dimensions are $10.39 \; x \; 8.46 \; x \; 2.44 \; inches$ [5].

We discussed the FBM0-AAQ-13688 sensor, this sensor is very cost-effective, low in cost, very easy method to use, the accuracy of the measurement is very high, and the output voltage in terms of the analog signal is 0 – 5 volts or 0 – 3 volts directly. The important property of the solution is always the PH of that solution. If we used industrial-grade PH meters, those meters are much more expensive. The range of this sensor is 0 – 14 PH value and in terms of temperature, it will measure 0 – 60.

SEN0169-V2:

The sensor from the manufacturer DFROBOT has a supply voltage rating of 3.3V to 5V and output voltage rating of 0V to 3V. Also its response time is less than one minute. This is an industrial grade sensor. The package dimensions are 1.97 x 1.18 x 0.79 inches. It also functions as a temperature sensor and measures temperature from 0 to 60℃ and weighs 10.23 ounces [6].

11.9.1. pH Sensor Comparison:

Keeping in view all the features of both the sensors from the manufacturer DFROBOT and DONGKER, the sensor from DONGKER is chosen to be used in this project. The reason for this selection is that both the sensors from the manufacturer have nearly the same features but the sensor from DFROBOT has industrial grade quality and also the difference lies in the price.

The sensor from DFROBOT costs around $69.9 while that of the DONGKER costs around $37. There is a huge price difference in both the sensors and our project objectives can be achieved using the sensor from DONGKER.

11.10. TIP-122 Transistor:

The purpose of the TIP 122 transistor is to switch the pump and the UV lamp ON and OFF. It is a Darlington pair NPN transistor but since it has a Darlington pair inside it has good collector current rating and gain.

It is mostly used to control loads with high current or in applications where high amplifications are required. Also it has a low base-emitter voltage(5V) allowing it to be controlled by microcontrollers. The features of this transistor are given in Table 8.

The **TIP122** is an NPN transistor of Darlington pair. It's like a normal functioning transistor. It has a good current collector rate due to the presence of a Darlington pair transistor of about 5A and it's about gaining 1000. It's like a collector of 100V. It can also drive a heavy load Emitter. Inside the transited has Darlington shows the internal circuit very clearly.

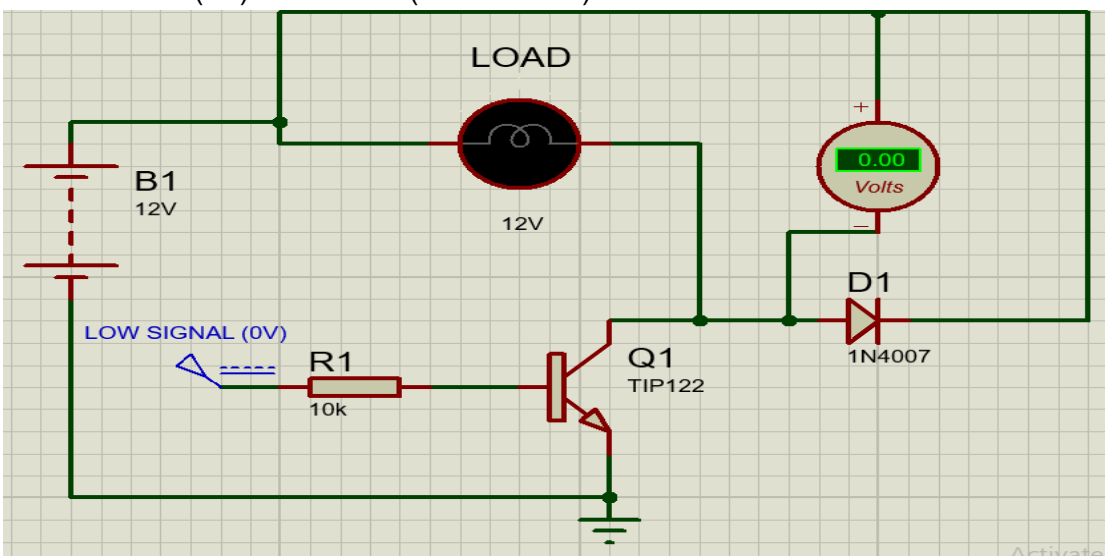
There are two transmitters which are present inside you can see clearly that the TO-220 package in which one is connected with another side of the second transistor First one is an emitter the second is a collector as they are tighter from a Darlington pair. Current rating of this transistor and also increase the gaining of current

The high current gain is called a transistor which is about (hfe = 1000) and also the collector that is connected to the high one (IC =5A). The higher implications also are necessary and required and the other is control and with the high rate of current. This transistor has a low Base-Emitter Voltage which has a 5V like microcontroller used as a Logical device as well which is about 120mA So as usual if you see the resistor it can also control the ideal choice So if you looking for a transistor it controls many different functions and uses for different application for the ideal choice as the high amplifier as the ideal one and control Power load.

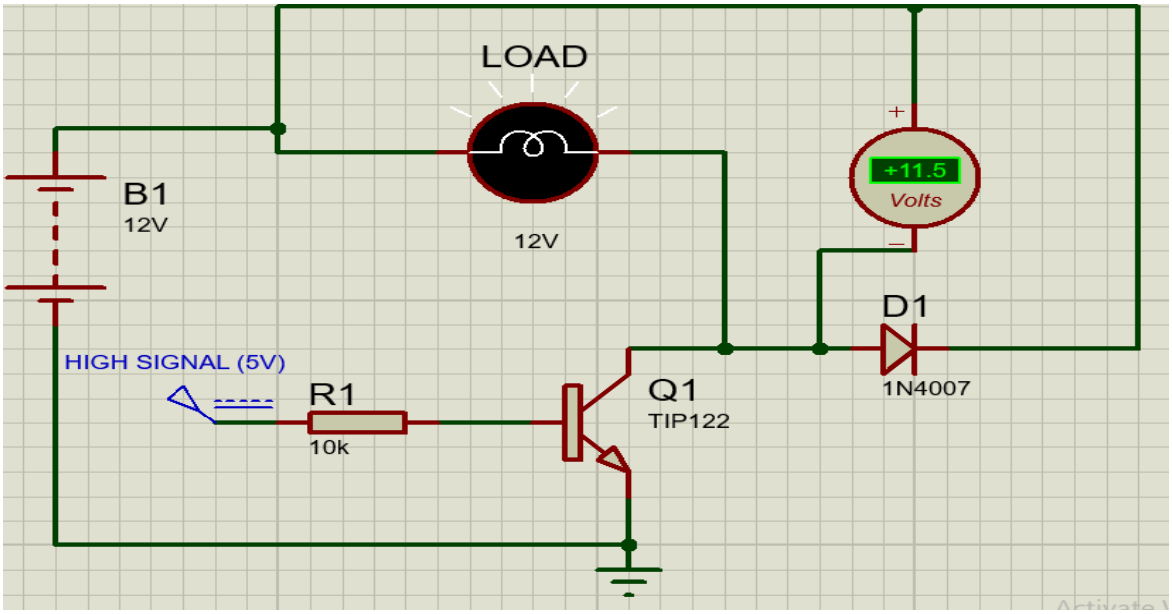
Table 8: Features of TIP-122 Transistor[7]

Feature	Value
Continuous Collector current	5A
Collector-Emitter Voltage	100V
Collector-Base Voltage	100V
High DC current Gain	1000
Emitter Base Voltage	5V
Base Current	120mA

LOW SIGNAL (0V) TO TIP122 (NO POWER)



This circuit is simulated in proteus to analyze the working of TIP122 Switching Transistor.Base is connected to 10K Resistor . Connecting the resistor to DC Source and setting the voltage to 0V .By running the simulation in the proteus it is analyzed that no voltage on the output of the transistor. DC voltmeter shows 0V but when signal change to HIGH (5V) DC Voltmeter shows 11.8V on the OUTPUT.



11.11. FTDI Converter:

The FTDI programmer is a 6-pin module which allows the user to connect a second device to the hardware serial port on an Arduino uno without compromising its ability to bootload. The

FTDI converter is used to program the microcontroller ATmega328 without using the Arduino UNO.

The reason for using this programmer is because it is easy to use and among the ATmega328 Microcontroller, many of the other Microcontrollers can also be programmed using this module. This module is also inexpensive, costing only $1.85 on AliExpress. It is powered using a USB port and runs on 3.3V to 5V [8].

The FTDI cable is the serial USB convertor which is directly connected with the TTL interface and the device that is USB one. FTDI cable is used for the configuration used in operating the 5av of 1/o pin which is FT232RQ one around as well. It is that which is connected to the USB connector. The 0.1 pitch is another side of the connector that is 0.1 pitch has different pin connector which us following pinout RTS, TX, CTS, GND. The GND like a black one and the other is a green one cable RTS.

The pinout of the cable is like functionality as our FTDI board that is the basic breakout. Arduino pro is used for the programmer as well pro mini and lilypad as an aligned green and black wire of FTDI cable.

The FTDI cable has cons and pros as the FTDI basic to FTDI cable as an indicator one. Its also have a Mini-B like a cable. FTDI is one of the main having protected to the element which is against but the project as the project. The basic FTDI is used as the DTR as connected with hardware rest one RTS signal as the FTDI cable.

11.12. Voltage Regulator:

The purpose of the voltage regulator in this project is to provide fixed voltage of a certain value which remains constant regardless of the changes to its input voltage or load conditions. The design concept calls for a an operational duration of at least two weeks. This requires either a battery sufficiently large to supply the load on its own for two weeks, or the use of an AC power supply.

Used alone, however, an AC power supply would be subject to power failure and render the system inoperable. This would adversely impact reliability. Therefore, an AC power supply with battery backup is the most desirable.

The devices chosen for hardware require a stable DC voltage source of power. !2VDC switching power supplies and batteries are commonly available, and provide appropriate power for a range of devices. In particular, the peripheral devices needed to administer plant resources, such as a water pump and LED light, can be obtained more cheaply as 12VDC devices.

For this reason, the system design assumes a 12VDC source of input power. Although the switching power supply in combination with a battery is likely to provide a stable input, the

system design includes voltage regulation so that it is not dependent on either a stable AC adapter nor a battery.

However, the microprocessor options considered rely on a DC voltage no higher than 5.5V and must be regulated for reliable operation. A lower voltage would reduce power and enhance operational duration, but must be high enough to assure reliable operation. Other components in the system also require a low voltage, and can affect the stability of the power source.

These variations would impact the sensors, where a stable working voltage is critical to enable proper readings. Thus, a voltage regulator will be used to provide the microprocessor and sensors with a stable operating voltage.

There are two types of voltage regulators: Linear Regulator and the Switching Regulator. The switching regulator is needed if the required voltage is higher than the input. In our design, there is no need to increase voltage once we have obtained the 12VDC supply voltage. Therefore, we will use linear regulators to provide the lower voltage required by the microprocessor and sensors.

The two devices that are considered for the purpose of voltage regulation are a Buck Regulator and an LM7805 integrated circuit.

11.12.1. Voltage Regulation Comparison:

A buck regulator is efficient and variable. It is similar to a buck converter in that it reduces the DC voltage to a lower value, but as a regulator it is designed to maintain a constant DC voltage despite fluctuations in the input voltage.

It is 85%-95% efficient in terms of power loss and does not require a heat sink. However, even a simple design requires many more parts and adds complexity to the system, as shown in the figure below. Simplicity of design is one of the engineering targets.

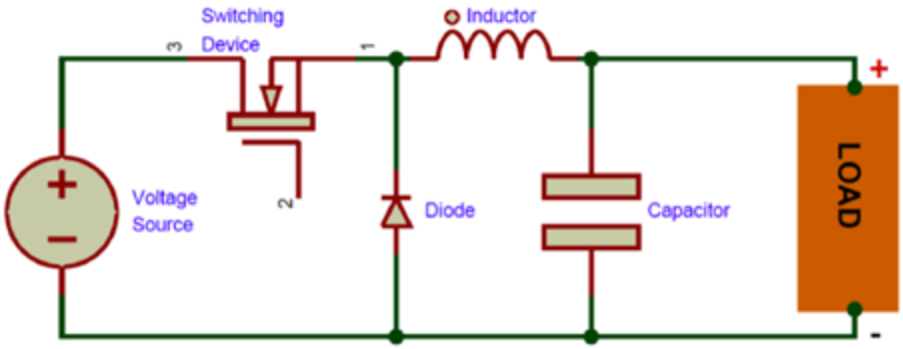


Figure 17: Buck Regulator circuit example

The LM7805 regulator has a simple design and one part. The LM7805 regulator chosen in the parts list has little noise compared to the buck regulator. It can provide a stable 5VDC required for the microprocessor and sensors. The simplicity of design also results in a lower cost. The LM7805 costs less ($0.66 to $1.5 [9]) compared to the Buck converter which is estimated to cost $4 to $15 in parts [10]).

The simplicity of voltage regulation using the LM7805 is illustrated in the following figure.

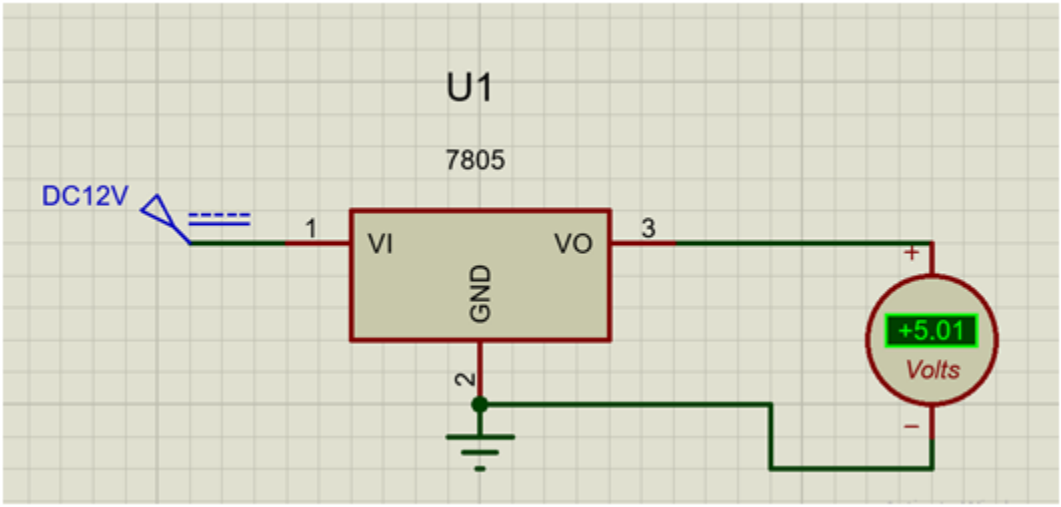


Figure 18: LM7805 Regulator circuit example

Operation of the LM7805 is very straightforward. The input voltage of 12VDC is applied between the input pin and the GND Pin. The ground pin is common and the output voltage

appears between the output pin and the GND pin. The common ground also simplifies the design. When tested with a DC Voltmeter, the LM7805 reliably convert 12V into 5V.

Pin Configuration:

Pin Number	Pin Name	Description
1	Input (V+)	Unregulated Input Voltage
2	Ground (GNd)	Connected to Ground
3	Output (Vo)	Outputs Regulated +5V

The simplicity of the external design belies the internal circuitry of the ML7805 chip. The is shown in the figure below.

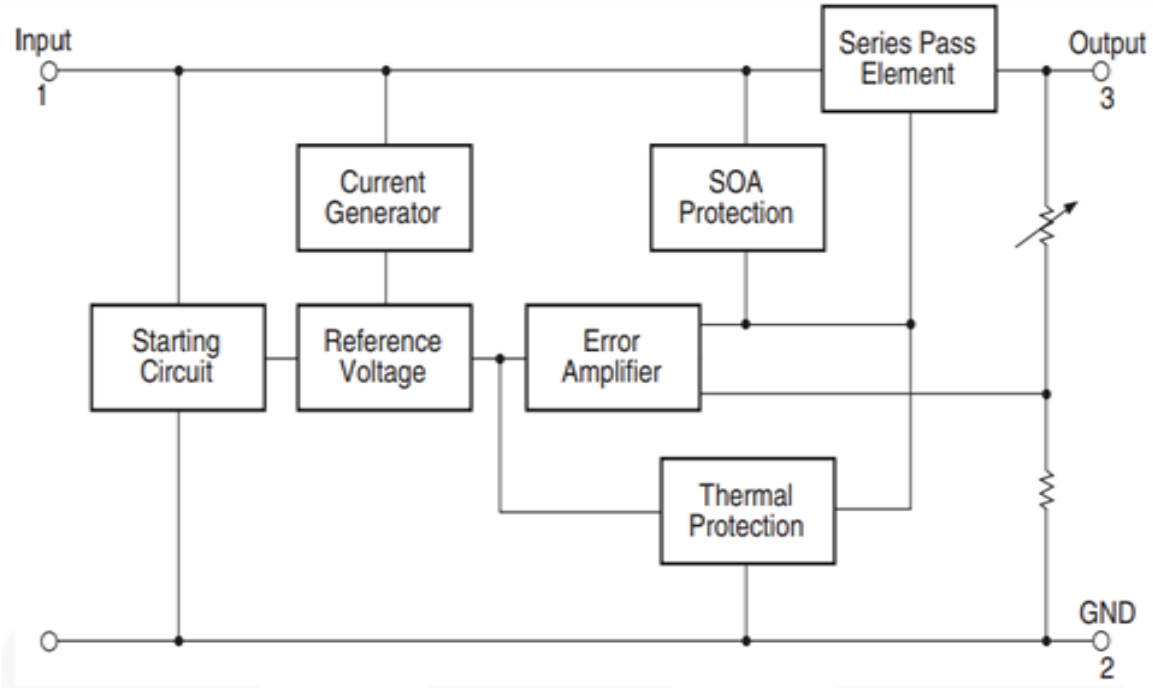


Figure 19: LM7805 Regulator internal circuitry

LM7805 Features

The LM7805 also provides useful features that enhance system reliability.

- · Thermal overload protection. Unlike the buck converter, there is power loss in the LM7805 that results in heat. Thermal protection is an important feature to insure system reliability. Failure of the voltage regulator due to excessive heat could damage other components.

- · Internal Circuit Limitation for current. This feature protects against short circuits. Given that several external sensor devices will be attached, the possibility that a short circuit will occur is very real. By limiting current in the regulator, the regulator mitigates the impact of circuit faults.

11.13. Crystal Oscillator:

The clock oscillator function is to control the speed of the digital processors in the microcontroller. Digital processors operate on the up/down cycle of the clock, and the frequency of the clock determines the base rate of all computations.

Clock oscillator circuits are sometimes included in the internal circuits of a microcontroller, controlling how quickly the processor runs. Alternatively, external clock oscillator circuits can be built that provide a variable frequency for more flexible operating capabilities. The simplest clock oscillator uses a quartz crystal.

The micro controller chosen for IPMS does not include an internal oscillator. The most reasonable alternatives are a voltage controlled oscillator capable of variable frequency selection, and a fixed frequency crystal oscillator. The design does not require a complex variable oscillator circuit. Therefore, the IPMS design is based on use of a quartz crystal oscillator.

Quartz crystal oscillators are made from high-quality quartz crystal wafers. Quartz is a piezoelectric material, which expands and contracts with the application of an electric current, which alters its electrical characteristics.

By feeding the current back into the crystal, a resonant frequency of oscillation is produced. The resonant frequency is determined by the size and shape of the crystal, which will produce

a single resonant frequency. Crystal oscillators are suitable for circuits requiring a frequency below 100MHz.

Our system will use a crystal oscillator at an even lower frequency. Quartz crystals generate series and parallel resonance. The series resonance is normally lower than the parallel resonance by several kilohertz.. In operation, crystals in the lower frequency range are generally operated between series and parallel resonance, which means that the crystal appears as inductive reactance, The inductance forms a parallel resonant circuit with an externally connected capacitor in parallel. If a small additional capacitance is added in parallel with the crystal, it results in an even lower resonant frequency. The effective inductive reactance of the crystal can be further reduced by adding a capacitor in series with the crystal. This has relatively small effect, but is often used to adjust the frequency of oscillation to a precise value within a narrow range. Reducing the reactance by adding a capacitor in series with the crystal raises the frequency of oscillation. To operate at its specified frequency, the components of the electronic circuit must exactly match those specified by the crystal manufacturer.

These adjustments are necessary because crystal oscillators in this frequency range do not usually oscillate at precisely either of its resonant frequencies. Thus the additional circuitry is needed to adjust the actual frequency of oscillation to the required value.

The crystal oscillator is also affected by temperature. Physically, the crystal's frequency characteristic depends on the shape or "cut" of the crystal. These have a shape similar to the traditional "tuning fork", whose length determines the frequency of oscillation. In general, crystal oscillators are manufactured under the assumption that they will be used at room temperature, about 71 degrees fahrenheit. Further, they are cut so that the frequency dependence on temperature is quadratic.

$$f = f_0 \left[1 - 0.04\ \mathrm{ppm}/^\circ\mathrm{C}^2 \cdot (T - T_0)^2\right]$$

As a result, any derivation from room temperature, whether negative or positive, causes the frequency of oscillation to decrease. This deviation could result in a clock based on a crystal oscillator losing several minutes per year if the temperature of its environment is not maintained at room temperature.

In the case of IPMS, it is not clear that a precise value is required, however. Our design does not include features dependent on a time of day clock. We only need a frequency of oscillation that ios usable by the microcontroller.

The crystal oscillator chosen for IPMS provides a stable fixed frequency oscillation of 16MHz. It is recommended for use with the ATmega328 microcontroller. The crystal oscillator itself contains only two connections. It provides the equivalent of the circuit shown below, tuned to the specific design frequency.

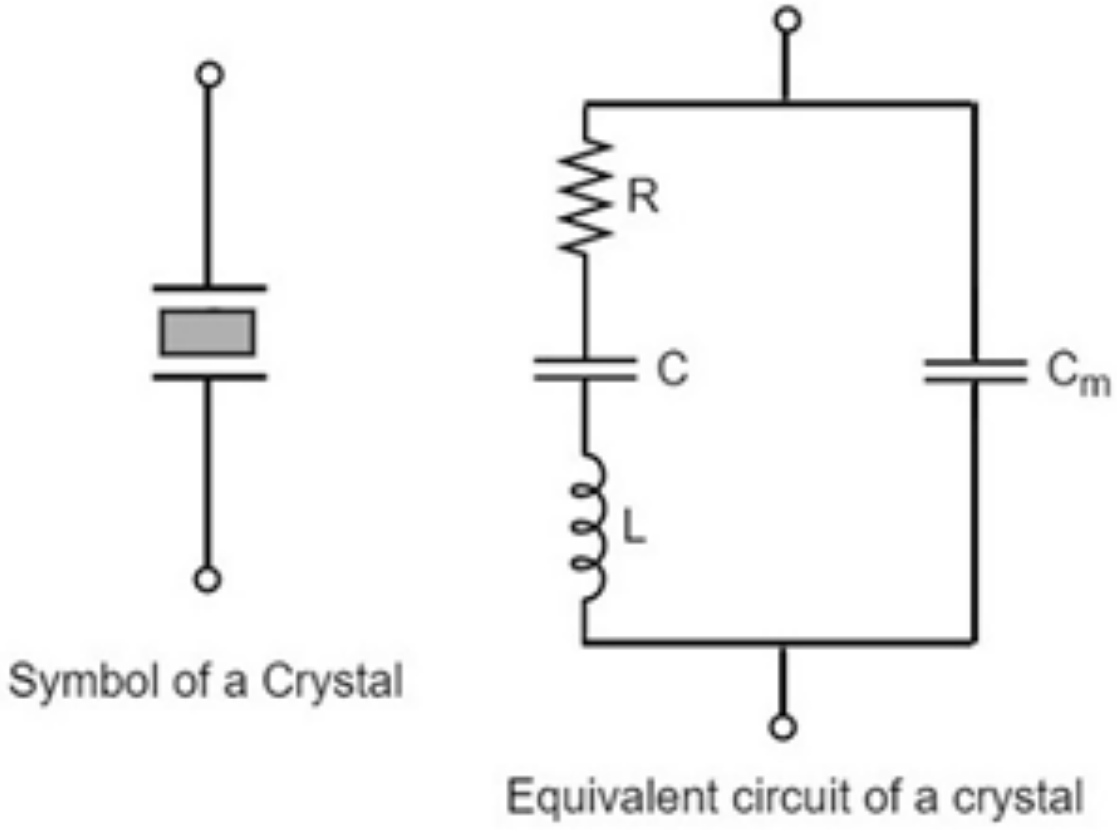


Figure 20 : Crystal Oscillator and Equivalent Circuit

The part chosen is HC49S 49S, which is very small in size at only 11.5*4.5*3.68mm and available from many sources. It is also very cheap, and will probably have to be purchased as a small lot of 10, but still less than $1.00.

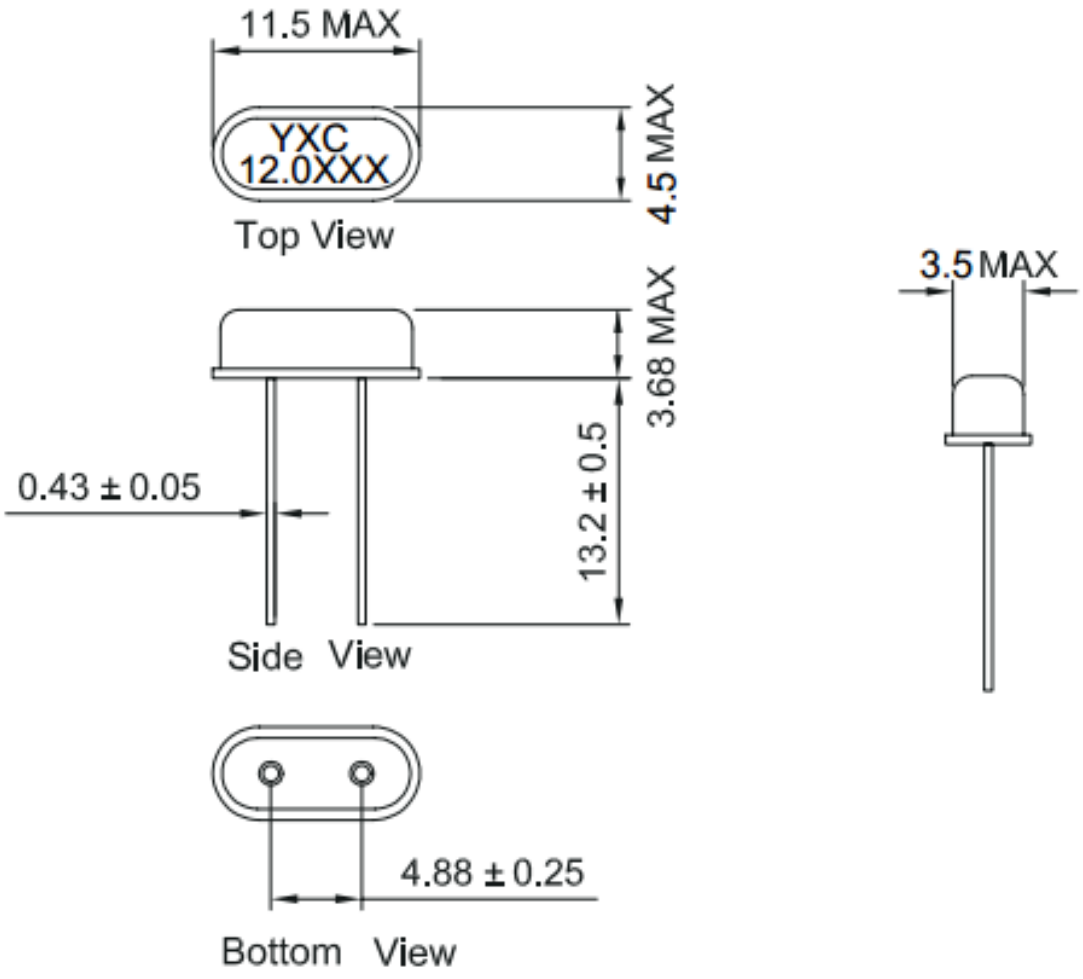


Figure 21 : Crystal Oscillator Physical Characteristics

11.14. Light Sensor:

The light sensor is required to measure the amount of light reaching the plant. There are several ways to accomplish this, grouped into two categories.

The first category is photo-voltaics. Photo-voltaic cells can generate an electrical signal that varies with the amount of light received. Within this category are devices that produce a voltage proportional to wavelength, produce a current proportional to light energy received. Either one could then be interpreted by the IPMS system to indicate the level of light reaching the plant. However, photo-voltaic cells tend to be relatively fragile and expensive. Also, they produce a signal that is independent of the IPMS, which would make them more difficult to manage.

The second category is passive photo-sensitive devices. These use materials whose electrical properties change in response to light energy. One type are semiconductors that control the flow of electrons across their PN junction. These can be constructed to be very responsive and sensitive to particular wavelengths of light. These are commonly used as receivers in signaling applications. The other type are photo-conductive devices which change their resistance when subjected to light. These are less precise and slower to react.

The IPMS does not require a highly responsive detector. Although sensitivity to ultraviolet would be preferable, it is not essential. A simple photo-resistor can provide the level of sensitivity and precision necessary to meet the engineering target. For this reason, a light dependent resistor (LDR) has been chosen for the light sensor.

The LDR is made from a piece of exposed semiconductor material such as cadmium sulphide that changes its electrical resistance from several thousand Ohms in the dark to only a few hundred Ohms when light falls upon it by creating hole-electron pairs in the material.

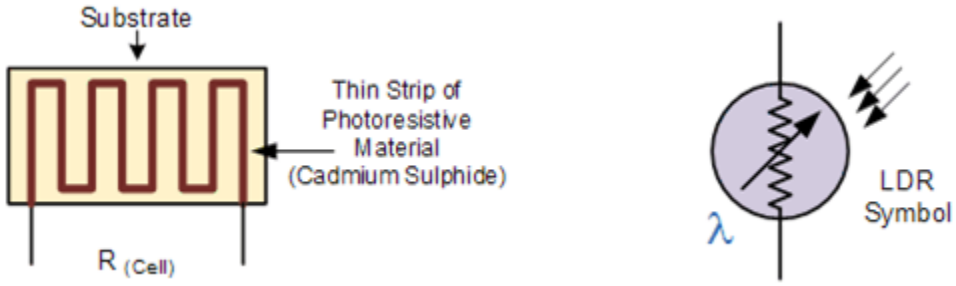


Figure 22 : LDR Construction

The net effect is an improvement in its conductivity with a decrease in resistance for an increase in illumination. It has a relatively long response time requiring many seconds to respond to a change in the light intensity.

The purpose of the LDR is to control the UV lamp so that the required amount of radiation can be provided to plants for their growth. When the resistance of the LDR changes in proportion to the intensity of the light, this can be interpreted by the Microcontroller to estimate the light level . However, the response is non-linear, and must be converted to a light intensivity based on its particular performance curve. A typical performance curve is shown in the following figure “LDR Performance Curve” (from “Light Sensors”, https://www.electronics-tutorials.ws/io/io_4.html):

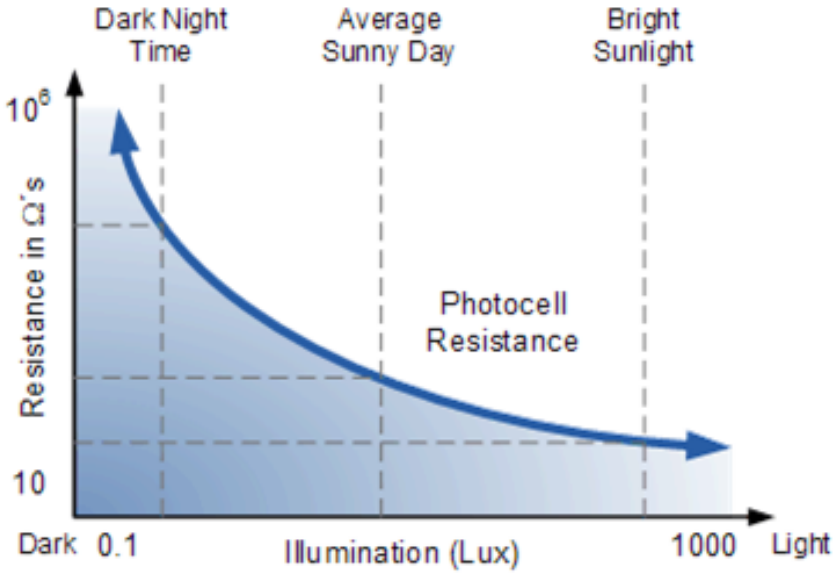


Figure 23 : LDR Performance Curve

The LDR is a simple component with only two connections as shown in the illustration below. It functions as a resistor.

Figure 24 : LDR Illustration

A typical LDR cost around $0.05. It is likely to consume about 100mW of power, dependent on the voltage applied, but this can be done intermittently. It generates a small amount of heat and is very heat tolerant and is not operationally impacted by temperature.

Programming and a set value turns ON and OFF the UV lamp [12]. A 5mm LDR has been chosen because it fulfills the needs of the project.

LDR Physical Characteristics:

1. Diameter: 5mm
2. No. of Pins: 2
3. Type of Mounting: Through Hole
4. Maximum Operating Temperature: +800C
5. Dark Resistance: 1-20M ohm

11.15. Temperature and Humidity Sensor:

Ambient temperature is a critical piece of information to maintain a houseplant. Many plants are considered houseplants because they cannot tolerate the outside temperatures in their geographic location. To a lesser extent, humidity is another important factor. Certain plants require very high or very low humidity to thrive. In most cases, higher humidity is helpful.

It is not clear what can be done to change the temperature or humidity other than to alert the homeowner. Temperature *might* be controlled with a remotely accessible thermostat and/or heater that are now available using WiFi and the internet.

Humidity *might* be raised using a water mister attached to a pump. However, at this point neither of these are within scope of the project except as potential additions because they require substantial external resources. The current concept for the IPMS is a simple homeowner device. With these additions, it might become suitable for a small greenhouse.

However, even if the IPMS lacks control features, the temperature and humidity affect the other plant needs. At higher temperatures, plants usually grow faster and need more water. If humidity is very low, plants will also need more water. Thus, knowing the temperature and humidity will be helpful even if they can not be controlled.

In the case of IPMS, we do not require continual monitoring nor high precision. Simple and inexpensive sensors will best meet the engineering targets.

Temperatures are readily observed using thermistors. The resistance of a thermistor is linearly proportional to the temperature, They are common in many devices.

Less common are humidity sensors. A capacitive humidity sensor measures relative humidity by placing a thin strip of metal oxide between two electrodes. The metal oxide's electrical capacity changes with the atmosphere's relative humidity.

Although these devices can be obtained separately, the least expensive option suitable for the IPMS is a combined device, Two options were found from the same manufacturer, DHT11 and DHT22. The DHT sensors are made of two parts, a thermistor and a capacitive humidity sensor.

There is also a very basic chip inside that does some analog to digital conversion and outputs a digital signal with the temperature and humidity. The digital signal is fairly easy to read using any microcontroller.

The DHT11 is an ultra low-cost digital temperature and humidity sensor. It uses a capacitive humidity sensor and a thermistor to measure the surrounding air, and outputs a digital signal on the data pin (no analog input pins needed). Its fairly simple to use, but requires careful timing to grab data. The only real downside of this sensor is you can only get new data from it once every 2 seconds,

The DHT22 is similar. It also uses a capacitive humidity sensor and a thermistor to measure the surrounding air, and outputs a digital signal every 2 seconds. Compared to the DHT11, this sensor is more precise, more accurate and works in a bigger range of temperature/humidity, but its larger and more expensive. DHT22 also comes as a wired version (AM2302) in a plastic case so that it can be remotely mounted.

Although the DHT11 sensor is less precise, less accurate and works in a smaller range of temperature/humidity, it is smaller and less expensive. Given our engineering priorities we have chosen this device, as shown below, for the system..

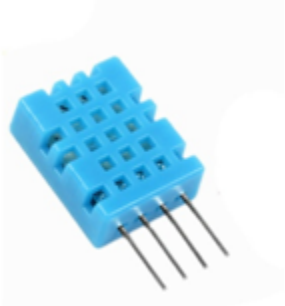


Figure 25 : DHT11 Temperature and Humidity Sensor

The DHT11 sensor has the following performance characteristics:

- Low cost ($5.00)
- 3 to 5VDC power and I/O
- 2.5mA max current use during conversion (while requesting data)
- Good for 20-80% humidity readings with 5% accuracy
- Good for 0-50°C temperature readings ±2°C accuracy
- No more than 0.5 Hz sampling rate (once every 2 seconds)
- Body size 15.5mm x 12mm x 5.5mm
- 4 pins with 0.1" spacing
- Compatible with Arduino microprocessors.

Connection of the DHT11 is quite simple. Although there are 4 pins, only three are used. Two are for power, and the third provides bi-directional communication with the microcontroller. These connections are illustrated in the figure below.

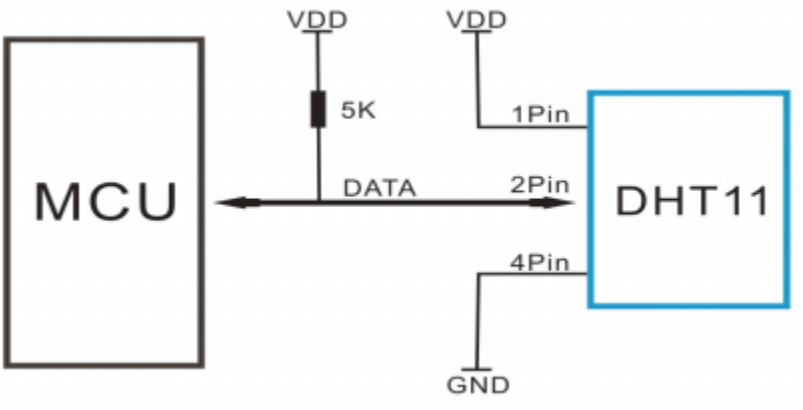


Figure 26 : DHT11 Connection to MCU

In the event that the DHT11 is determined to be inadequate, the DHT22 could be substituted for double the cost The DHT22 is slightly larger and is capable of reporting a wider range of temperatures and humidity, as shown below: We do not think it is needed.

- Inexpensive ($10.00)
- 3 to 5V power and I/O
- 2.5mA max current use during conversion (while requesting data)
- Good for 0-100% humidity readings with 2-5% accuracy
- Good for -40 to 80°C temperature readings ±0.5°C accuracy
- No more than 0.5 Hz sampling rate (once every 2 seconds)
- Body size 15.1mm x 25mm x 7.7mm
- 4 pins with 0.1" spacing
- Compatible with Arduino microprocessors.

The DHT11 signalling method uses variations in the width of a Full Wave Pulse as shown below:

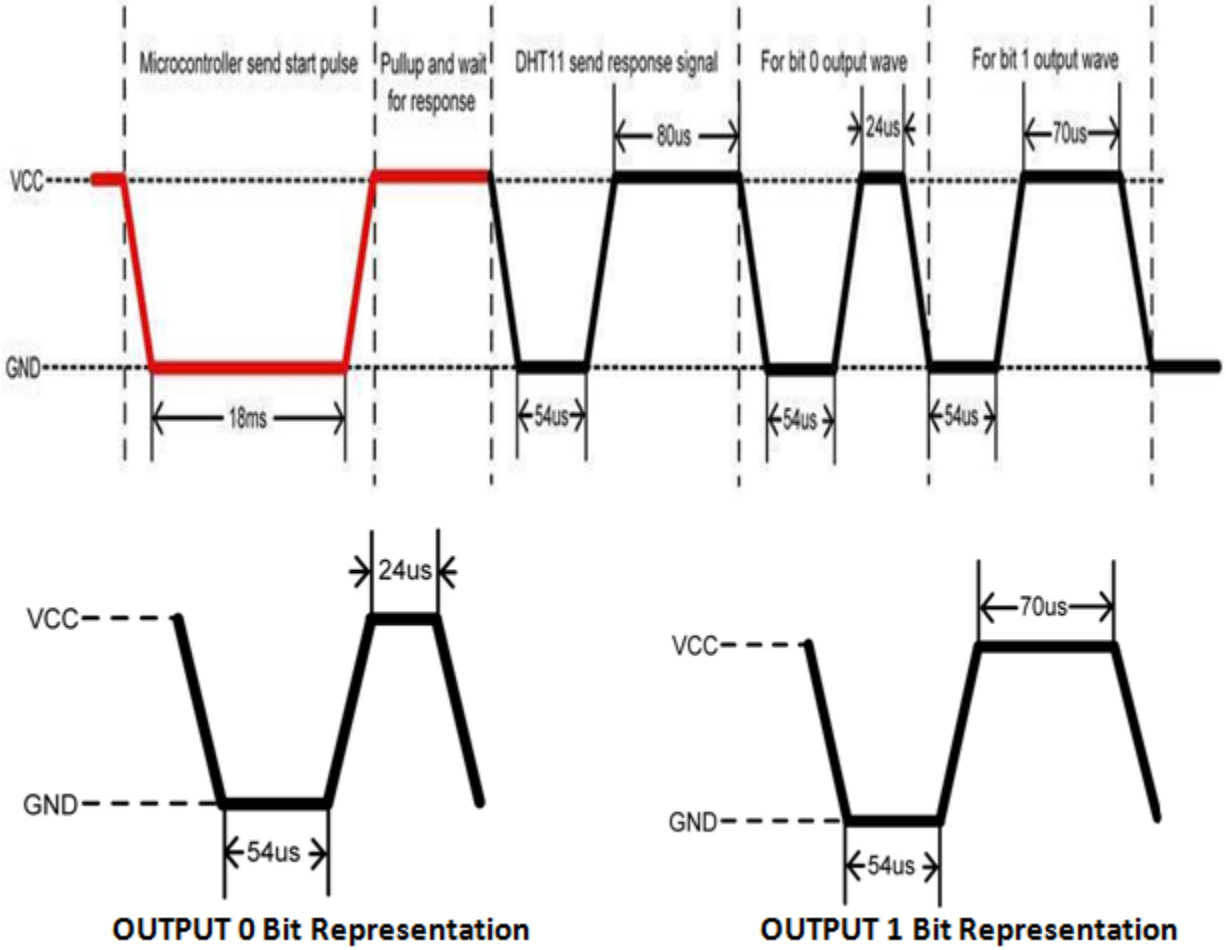


Figure 27 : DHT11 Digital Communications

11.16. Grow Light:

Most plants require light to enable photosynthesis to grow. Indoor plants are usually placed near a window to obtain adequate sunlight. However, this does not guaranty sufficient light. If a plant does not get enough light, it becomes weak and all other environmental conditions become increasingly critical for its survival. For this reason, the IPMS will monitor light levels and be capable of augmenting the light level if needed.

Although sunlight provides a wide spectrum of light, we know that ultraviolet light is especially useful to plants. IPMS can be more effective and use its resources more efficiently by providing ultraviolet light.

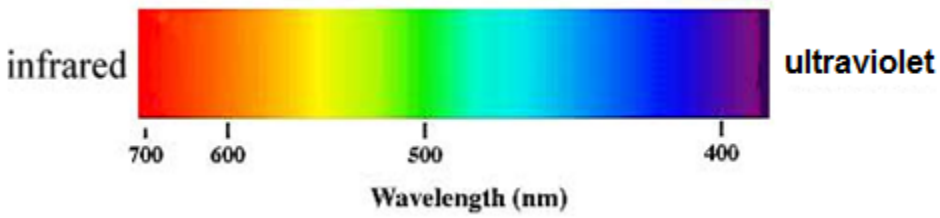


Figure 28 : Visible Light Spectrum

Ultraviolet (UV) light is difficult to provide using incandescent bulbs, since they produce light at the low (heat) end of the visible spectrum. Previously, fluorescent light bulbs were commonly used to create ultraviolet lighting. Both of these usually relied on a household power source of 110-220 volts.

A comparison of artificial grow-light options is summarized in the chart below, from "Albopepper Urban Gardening", http://albopepper.com/light-source.php.

INDOOR ARTIFICIAL GROW-LIGHT OPTIONS

	FLOURESCENTS			HIGH-INTENSITY DISCHARGE (HID)			LEDs
	CFL compact, spiral	**T8** linear, tube	**T5** linear, tube	**HPS** high-pressure sodium	**MH** metal halide	**CMH** ceramic metal halide	**LED** light-emitting diode
Spectrum:	Balanced	Balanced	Well Balanced	Warm (Yellow-Red)	Cool (Blue-Green)	Well Balanced	Custom (Balanced)
Initial Cost:	Low	Low	Medium	Medium	Medium	Medium - High	Low - High
Power Draw:	Low	Low	Medium	Medium - High	Medium - High	Medium - High	Low - High
Efficiency:	Fair	Good	Good	Better	Better	Best	Good - Best
Application:	Entry level. Good for short term use. Works as extra lighting near bright window or low watt LED. Fits tight spaces or as side lighting. Good for lettuce, seedlings & cuttings.	Not as efficient or as bright as T5s, but less expensive. Good for tight spaces like shelves. Potential heat source for cool spaces. Good for lettuce, seedlings & cuttings.	Most efficient fluorescent, but more costly. Very bright at close distances. Good for healthy, vigorous, growing projects like seedlings, cuttings, lettuce & small herbs.	Good for flowering & fruiting stages. Best for larger, mature plants in large areas. Requires extra vertical clearance. Higher light output & power draw. Cooling may be required.	Good for vegetative stages. Yields large plants. Requires extra vertical clearance. Good canopy penetration with higher light output & power draw. Cooling may be required	More expensive than MH or HPS, but more efficient & reduced heat output. Excellent broad spectrum color, for all growth phases. MH & CMH can leak UV light if damaged.	Good for all growth phases. Broad range of wattages. Spectrums are custom designed by mixing multiple diodes. Improved energy efficiency at higher price point.

Fluorescent lighting has been commonly used for many years. Compact fluorescent bulbs are easily fit into existing fixtures, but are not very efficient. T8 and T5 fluorescent tubes are slightly better, but require large and cumbersome fixtures. "HPS" refers to high pressure sodium, which provide a better spectral range and higher lumen output, but are uncommon, expensive, and require a lot of power. "MH" refers to metal halide, which is similar and also

requires a high power source. "CMH" is ceramic metal halide, which is the most expensive of the HID options. LEDs are the newest option, and provide a wide spectrum of light very efficiently. Recent advances in LED lighting enable very high output for very low cost.

The amount of light reaching the plant is a critical parameter. Lighting is usually measured in Lumens, the light output of the lamp. Few artificial light sources can match the output of sunlight. The following chart (from "An Introduction to Green Wall Lighting", https://www.newprocontainers.com/blog/_staging/introduction-green-wall-lighting/) illustrates typical plant light requirements in Lux, which is one lumen per square meter. Thus, the distance of the light source to the plant is also important. The design of some light sources - and the heat they produce - require placement at some distance which reduces the Lux at the plant surface.

Condition	LUX	Foot-Candles
Sunlight	107,640	10,000
Daylight	10,764	1,000
Overcast	1,076	100
Very Cloudy	108	10
Twilight	10.76	1

Plant Type	LUX	Foot-Candles
Low Light	500 - 2,500	50 - 250
Medium Light	2,500 - 8,000	250 - 750
High Light	5,500 - 10,500	500 - 1,000
Direct Sun	10,500 +	1,000 +

**ranges of LUX & FC are not exactly equal. I rounded the numbers to make the ranges easier to use as reference points.*

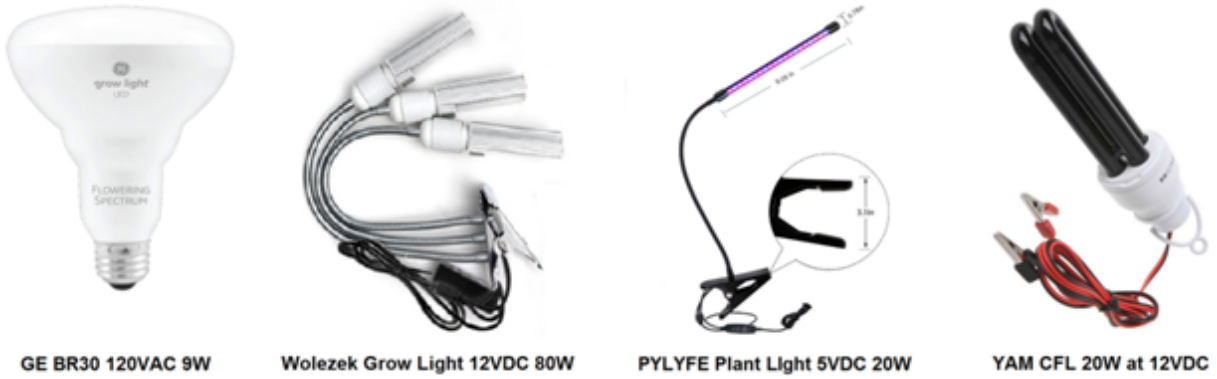
Although not exact, and dependent on the manufacture of the bulb, the following chart gives a reasonable estimate of Lumen per Watt for the most acceptable lighting source for IPMS:

Light Output	 Light Emitting Diodes (LEDs)	 Incandescent Light Bulbs	 Compact Fluorescents (CFLs)
Lumens	Watts	Watts	Watts
450	4-5	40	9-13
800	6-8	60	13-15
1,100	9-13	75	18-25
1,600	16-20	100	23-30
2,600	25-28	150	30-55

This shows that a useful light source for IPMS will have at least 10 watts if LEDs are used, and about 20 watts if CFLs are used.

Modern light emitting diodes (LEDs) provide an attractive alternative. If anything, LEDs favor the higher frequencies, and full spectrum LEDs are relatively inexpensive. LED lights are very efficient and do not require household power. In fact, the two most common power supplies used for LEDs are 12VDC and 5VDC.

To augment sunlight with an artificial light source for the indoor plants indoor, a 12V full spectrum lamp has been selected for use in this project. There are a number of small full spectrum lamps available in the market and their prices range from $10 to $20 [13].



GE BR30 120VAC 9W | Wolezek Grow Light 12VDC 80W | PYLYFE Plant Light 5VDC 20W | YAM CFL 20W at 12VDC

Figure 29 : Plant Light Alternatives

11.16.1. Grow Light Comparison:

- The 9W LED grow light bulb from GE has a conventional Edison screw base but requires 120VAC. We have no other components requiring 120VAC.
- The YAM model QXNA1AA600643 CFL uses 20W at 12VDC.
- Wolezek produces a tri-head 80W LED grow lamp that uses replaceable 12VDC bulbs with a conventional screw base.
- PYLYFE has a 20W LED grow lamp that runs on 5VDC. Being 5VDC means that it requires higher amperage for its 20W output.

While the LED lamps are more efficient and produce more lumens per watt, the CFL lights are cheaper. The UV lamp from YAM is selected for providing light to plants because it has the lowest cost, and keeping costs low is an important engineering target. It costs around $8.34 and has a power rating of 20W [15]. It also operates on 12VDC, which we can supply with our planned power supply.

If a replacement light bulb from Wolezek could be found, that might be substituted, since it would provide more lumens for the same power consumption.

11.17. Water Pump:

The primary resource needed by plants when unattended is water. Moreover, water needs to be applied at a proper rate. Too little or too much will kill the plant. The plant requirements vary depending on many factors. These will be input to the microprocessor which will then manage the water resource.

As with other peripheral attachments, there are a wide variety of alternatives. The IPMS does not require a high volume rate of supply. The amount of water, even for a large plant, should be delivered slowly. That will provide time for the water sensor to react, providing feedback to know when sufficient water has been applied. Several considerations were made with regard to how the water would be supplied.

Pressure hose versus tank:

- One alternative is to use a pressurized supply hose attached to a household water tap. In that case, the microprocessor could turn on and off a mechanical value. This is a risky approach, however. First, if there are any leaks, the pressurized supply could flood the house. Secondly, if the valve did not shut off properly, the plant would get too much water and again there is potential for a flood. Such a system would also lose a lot of portability and convenience, since it would depend on a connection to a water supply. For these reasons, the use of a pressurized supply hose has been rejected.
- Instead, the IPMS will use a small water pump to transfer water from a tank. The tank must be sufficient to supply watering needs for the expected duration of absence. Our engineering target is 2 weeks. For most plants, a tank of sufficient capacity is easily obtained. It might consist of a simple bucket, or an old milk carton. I can be as big or as small as needed for the circumstances. If there is any sort of failure causing water leakage, the most that can be spilled is the contents of the tank.

AC versus DC:

- Small AC pumps are available that use a vibrating diaphragm to pump. These are mechanically very simple and reliable. However, our power supply is direct current.
- Small DC pumps are available in many voltages. IPMS will have a 12VDC source, and regulated supplies at either 5VDC, 3VDC, or both.

Submersible versus non-submersible:

- Submersible pumps sit in the water tank and require no priming. They are more expensive, but assure that when turned on, they will not run dry because their lift capacity is too small. They are less prone to failure and are waterproof.
- Non-submersible must be mounted above the water level and are not waterproof. They must be able to create a strong enough vacuum in air to pull the water up out of the tank. Although less expensive, they are less durable and prone to failure. They also require additional care to set up. These characteristics have a negative impact on system operation, lifespan, and ease of use .

In consideration of these factors, and to minimize the load on the regulated power supply, IPMS will use a 12VDCsubmersible pump. For the purpose of selection two representative pumps available in the market have been considered.. These are the 12V submersible pumps from Wal Front and 12V vacuum pump from Yosoo Health Gear.

11.17.1. Water Pump Comparison:

On comparison the both the pumps have nearly the same features, the difference is between the flow rating, the input current rating and the pricing. Since the pump of Walfront has higher current consumption, it has a flow rating of 2L/min while its price is $16.29.

The pump from Yosoo Health Gear has a maximum flow rating of only 150mL/min and its price is $19.09. Keeping in view all these differences, pump from Walfront has been tentatively selected due to its low price and higher flow rating.

Table 9: Comparison of Pumps

Feature	Pump From Yosoo Health Gear[17]	Pump from Walfront[16]
Voltage Rating	12V	12V
Input Current	250-300mA	500mA
Flow	0-150mL/min	2L/min
Submersible	Yes	Yes
Weight	59 grams	60 grams
Price	$19. 09	$16. 29
Model	G528	–

According to experts, one of the biggest mistake made by people caring for plants is to set a fixed schedule. Rather, plants should be given mater when they need it, but only when they need it. Most plants do not need (or want) water until the soil is fairly dry.

Providing the proper amount of water is the most critical part of automated plant care. The primary advantage of the IPMS is that plants will not be watered constantly or on any set schedule, but only when the soil has mostly dried out. This is unlike most watering systems.

Watering might be needed as often as twice a day, or as infrequently as once a week. It depends on the environment, the soil conditions, and the type of plant. In fact, it would be even more varied. The IPMS moisture sensor can be set to determine when a plant needs water.

When water is needed, the watering systems should moisten the entire root zone. When manually watering, it is recommended that the plant should be watered until water comes out of the drainage hole in the bottom of the pot.

In the case of an automated system, we can sense the moisture deep in the pot and turn off the water when it is moist rather than waste water by letting it run out the bottom of the pot.

Some plants require as little as a tablespoon of water per day. On the other hand, it may take as much as ¾ or a gallon of water to thoroughly water a 10 to 12 inch plant container for thirsty plants. We need to have an adequate water supply to provide for the watering needs of a variety of plants. By using a submersible pump, we allow a lot of flexibility in choosing the tank holding water supply.

There are other factors which IPMS can take into consideration.

Most plants should not be watered at night or at the end of the day. Without light, plant growth slows to a stop, and roots will not actively take up water. With its light sensor, IPMS can adjust its watering schedule appropriately.

If the temperature is high, plants and soil lose more water to evaporation, and therefore need increased watering. IPMS includes a temperature sensor that can be used to adjust the watering rate.

Many plants also have seasonal needs. This may not be obvious in an indoor houseplant. However, there are some that require a period of rest corresponding to either the winter or summer season. IPMS settings will allow the user to adjust its settings to accommodate seasonal variations.

A summary of IPMS watering control is shown in the table below with anticipated minimum and maximum values. These are not absolutes, but expectations of design parameters that the design will accommodate. The frequency and amount are likely to be inversely proportionate.

Table 10: Control Control Design Parameters

Control Item	***Minimum***	***Maximum***	***Control***
Frequency	Weekly	Every 2 hours	Moisture sensor
Amount	One tablespoon	One gallon	Moisture sensor
Application rate	0.1 L/min	1 L/min	Not required
Time of day	Mornings only	24x7	Light sensor
Temperature	Near freezing	Hothouse	Temperature sensor
Seasonal	Dormancy	Rapid growth	User setup
Added nutrients	None	Soluble fertilizer	User supplied

12. Hardware Layout

The following sections describe the layout of the PCB board and connectors.

12.1. Microcontroller Block:

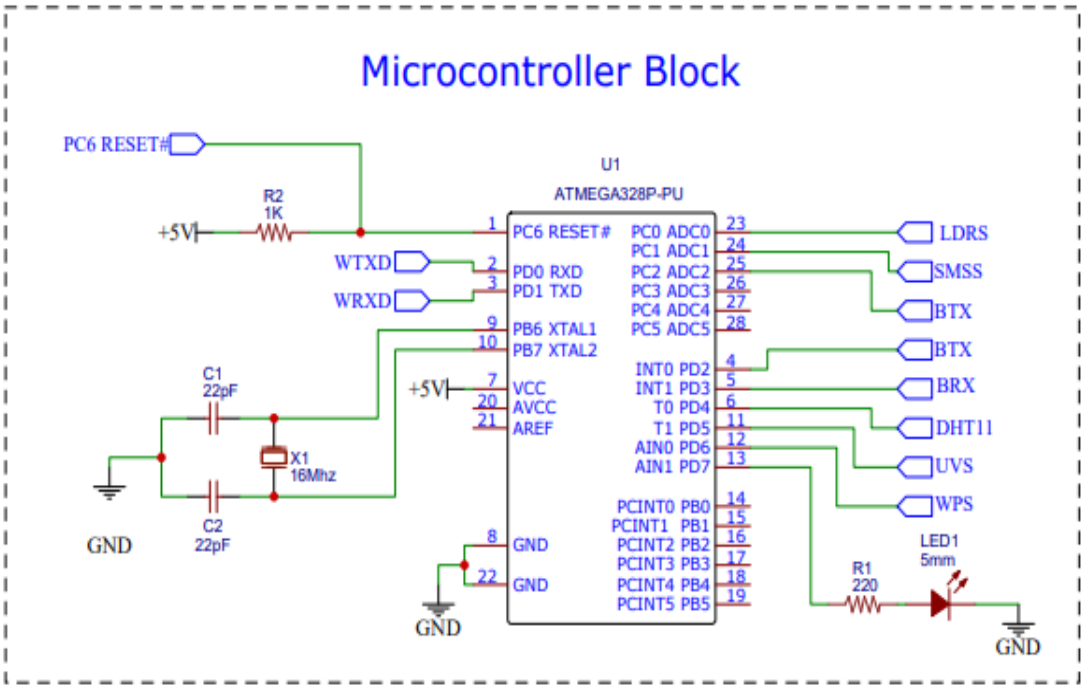
The microcontroller block schematic shows the connections of the various components to the Microcontroller. On pin 7(VCC) +5V are provided for running the Microcontroller. Both pin 8

and 22 are connected to the ground. Pin 9 and 10 are connected to crystal oscillator, two capacitor and ground to provide the Microcontroller with timing signals.

Pin 23(ADC0) is connected to the LDR so as to receive the output of the LDR through the AD0 pin. The number value received through the AD0 is from 0 to 1023. The temperature and humidity sensor is connected to the pin 4 which is the D4 (digital pin 4) of the Microcontroller. Pin 13(D7) is connected to a 220 ohm resistor which is connected to a 5mm LED, which is also connected with the ground.

A reset circuit which consists of a 1K resistor connected to a 5V supply and a push button is connected to pin 1(RESET #) for resetting the Microcontroller. The ultraviolet lamp is connected to the pin 12(D6) of the Microcontroller. The BTX and BRX connections are from the Bluetooth module which are connected at the pin 4(D2) and pin 5(D3) of the Microcontroller respectively.

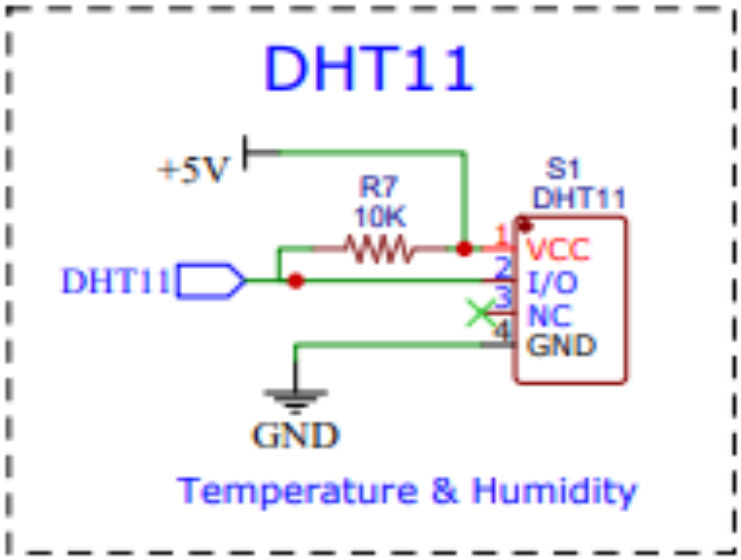
The SMSS connection is from the soil moisture sensor and is connected to the pin 24(ADC1) of the Microcontroller. The WTXD and the WRXD connection are from the Wi-Fi module which are connected to the pin2 and pin 3 respectively.



12.2. DHT11 Block:

The DHT11 is the temperature and humidity sensor. It has 4 connections. One connection is to the ground pin of the Microcontroller. While 5V are provided to the VCC. The DHT11

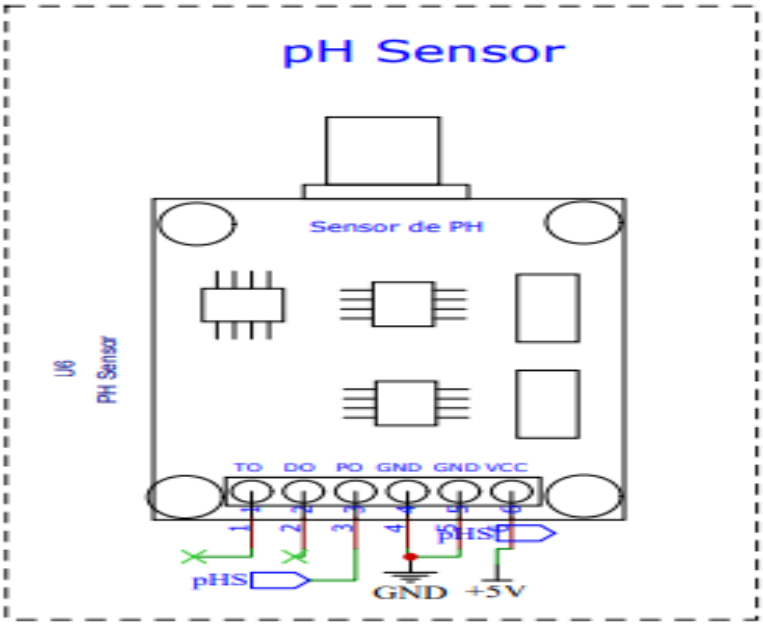
connection connects the I/0 pin (pin 3) of the DHT11 to the microcontroller pin 6(D4). A 10K resistor is also connected between the VCC and I/O pin.



Sr.No	Module	Microcontroller
1	Analog Pin (I0)	T0 PD4 (PIN 6)
2	VCC Pin	+5V of LM7805
3	GND Pin	-5V/ GND of LM7805

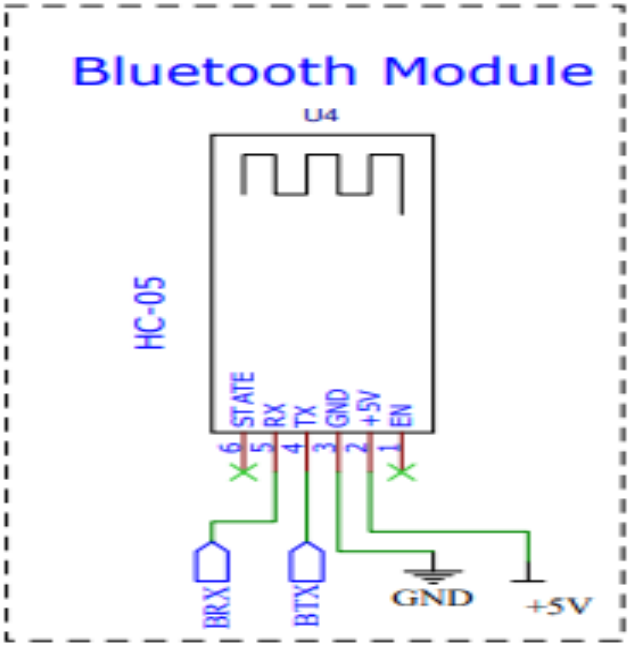
The pH sensor has five pins(T0,D0,P0,GND,GND,VCC). Both the ground pins are connected to the ground pin of the Microcontroller. +5V voltage is provided to the VCC pin while the pins T0 and D0 are not connected to any pin. The pin P0 is connected to the pin 25(ADC2) of the Microcontroller. The pH sensor sends data through the P0 to the Microcontroller.

Sr.No	Module	Microcontroller
1	Analog Pin	PC2 ADC2 (PIN 25)
2	VCC Pin	+5V of LM7805
3	GND Pin	-5V/ GND of LM7805



12.3. Bluetooth Module:

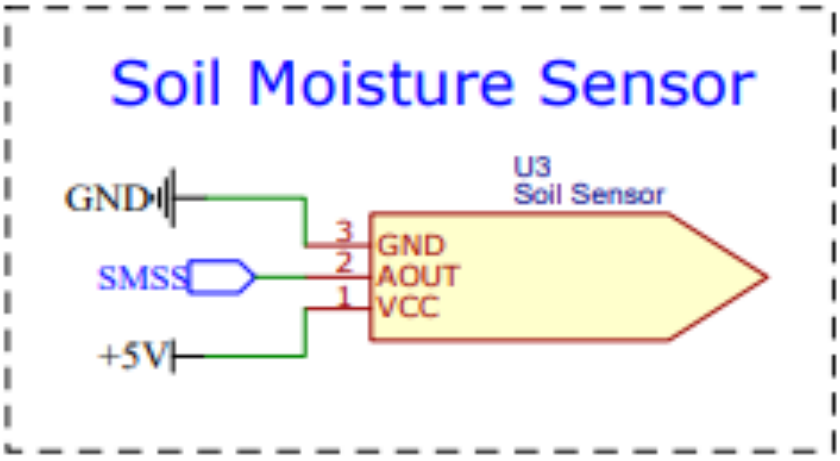
The Bluetooth module has six pins. +5V are given the VCC pin of the Bluetooth module. While the ground pin is connected to the ground pin of the Microcontroller. The RX pin of the Bluetooth module is connected to the pin 5 of the Microcontroller while the TX pin is connected to the pin 4 of the Microcontroller. The Bluetooth module sends and receives data to and from the Microcontroller using the TX and RX pins.



Sr.No	Module	Microcontroller
1	RX Pin	INT1 PD3 (PIN 5)
2	TX Pin	INT 0 PD2 (PIN 4)
3	VCC Pin	+5V of LM7805
4	GND	-5V/GND of LM7805

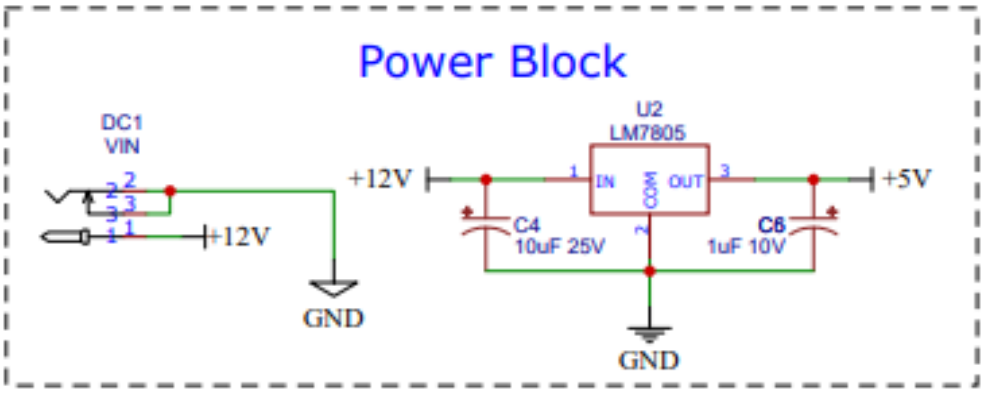
12.4. Soil Moisture Sensor:

The soil moisture sensor used in this sensor is capacitive type sensor. It measures the capacitance. It has three pins(GND,AOUT,VCC). The GND and VCC pins are connected to the ground and +5V of the Microcontroller. While the AOUT pin is connected to the pin 24 of the Microcontroller.



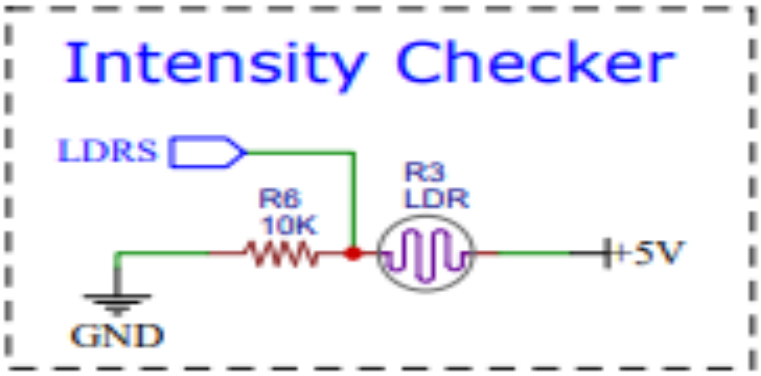
Sr.No	Module	Microcontroller
1	Analog Pin	PC1 ADC1 (PIN 24)
2	VCC Pin	+5V of LM7805
3	GND Pin	-5V/ GND of LM7805

12.5. Power Block:



12.6. Intensity Checker:

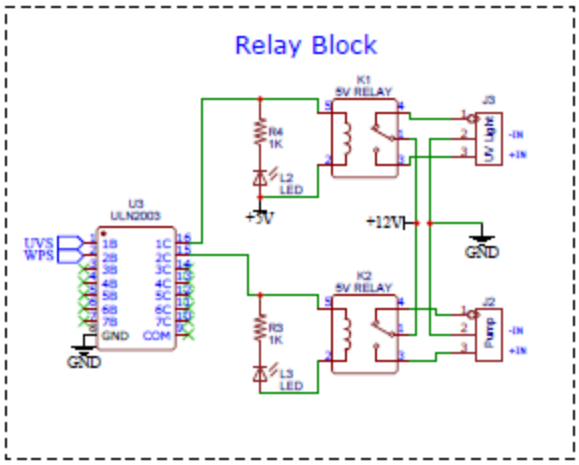
To check the amount of light (luminosity) present in the indoor plant monitoring system, an LDR is used. The LDR is connected to the ground using a 10K ohm resistor. Also +5V are given to it. The LDRS connection is the connection between the pin 23 of the Microcontroller and the LDR.



Sr.No	Module	Microcontroller
1	Analog Pin	PC0 ADC0 (PIN 24)
2	VCC Pin	+5V of LM7805
3	GND Pin	-5V/ GND of LM7805

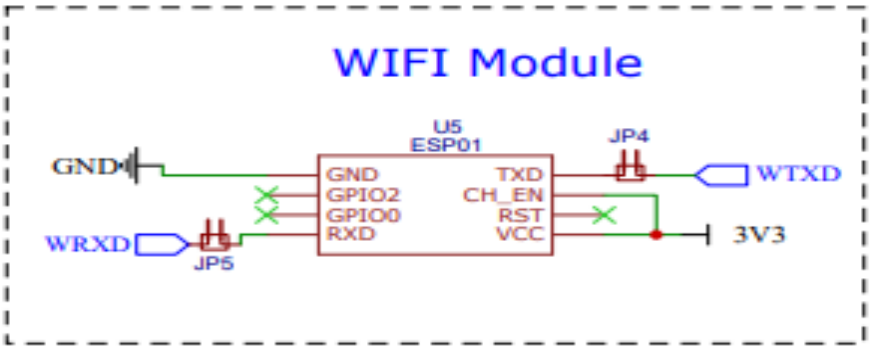
12.7. Relay Block:

We are using Single channel 5V relay having inputs and output pins, input pins are connected with microcontroller and +5V power supply. And output pins are connected with UV lights and pump.



12.8. Wi-Fi Module:

The purpose of the Wi-Fi module is to communicate with the Microcontroller and the smartphone. It has nine pins. GPIO2 and GPIO0 pins are not utilized. While the GND pin is connected to the ground , the VCC pin and RST pin is connected to the 3V supply from the voltage regulator. The RXD and TXD pins are connected to the pin 3 and pin 2 of the Microcontroller respectively.

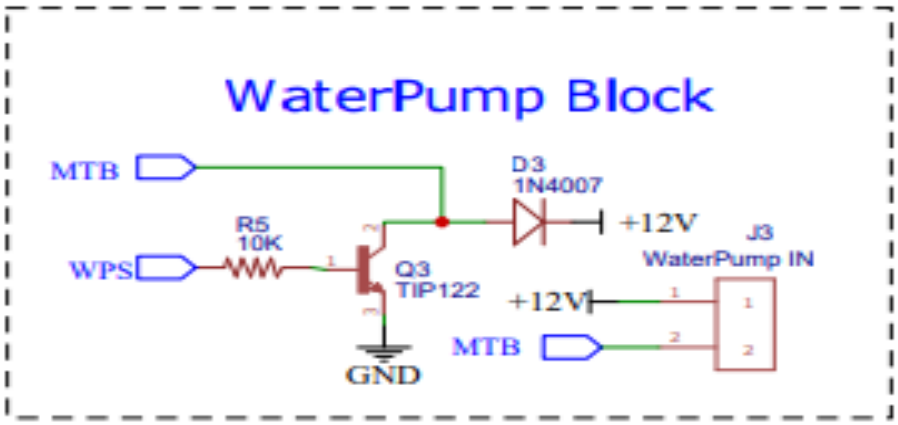


Sr.No	Module	Microcontroller
1	RX Pin	PD1 TXD (PIN 3)
2	TX Pin	PD0 RXD (PIN 2)
3	VCC Pin	+3.3V Microcontroller
4	GND	GND / -3.3V Microcontroller

12.9. Water Pump:

The water pump schematic is shown below. It contains a water pump along with a 10K ohm resistor, a TIP122 transistor which is used for the switching purpose and 1N4007 diode to

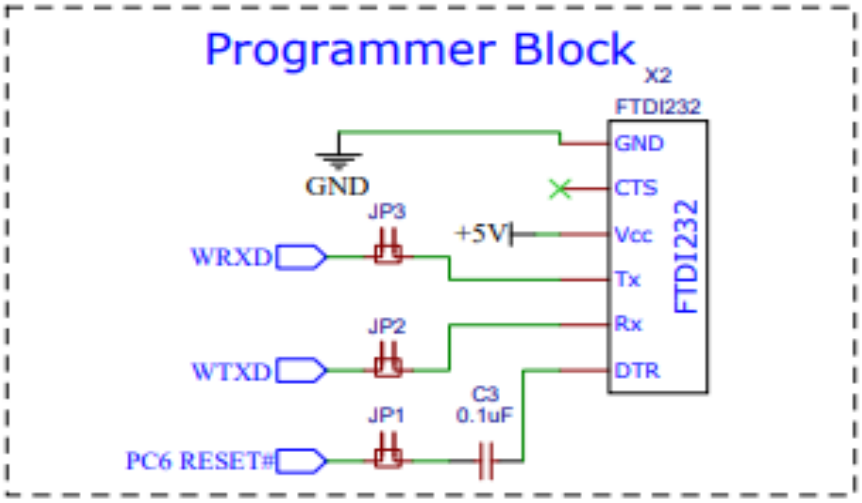
prevent back flow of current. The WPS connection is between the pin 1 of the TIP122 transistor and the pin 13 of the Microcontroller. At the pin 2 +12V are provided. While the MTB connection is between the pin 2 of the TIP and the water pump.



MPS : AIN0 PD6

12.10. Programmer Block:

To program the Microcontroller, an FTDI programmer is used which is versatile and easy to use as a programmer for the Atmega328 Microcontroller. At the time of programming the TX and RX pins of the FTDI programmer are connected to the TX and RX pins respectively. +5V are provided at the VCC of the FTDI232 and other connections are made according to the schematic.

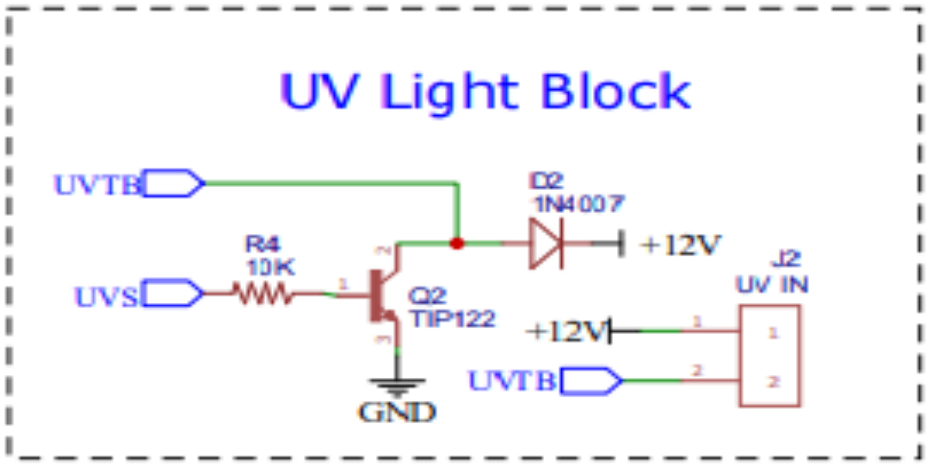


Sr.No	Programmer	Microcontroller
1	RX Pin	PD1 TXD (PIN 3)
2	TX Pin	PD0 RXD (PIN 2)
3	VCC Pin	+5V

4	GND	GND
5	DTR	PC6 RESET#

12.11. UV Light Block:

The UV light provides the necessary light for the completion of the photosynthesis process in plants. The UV light schematic is given below. IT contains a TIP122 transistor for switching purposes along with a 10K ohm resistor and 1N4007 diode. The UV light is connected to the pin 2 of the TIP transistor. +12V are provided to it on pin 2.



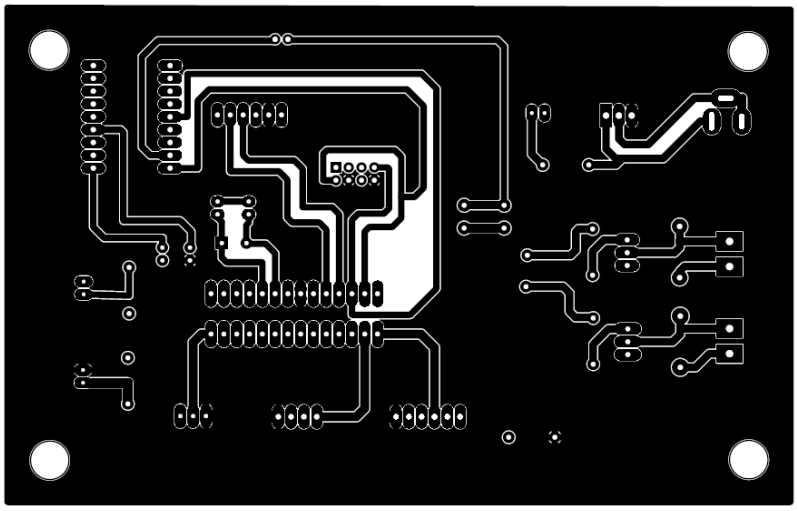
UVS: T1 PD5 (Pin 11)

12.12. PCB Prototype models:

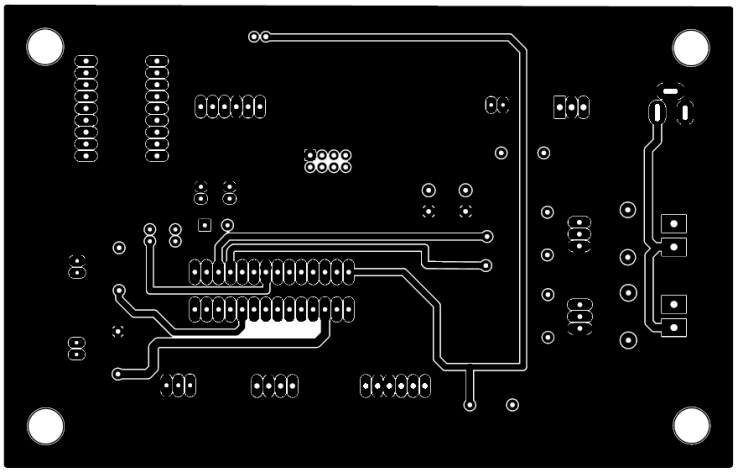
We are using two working PCB designs one is using Buck Converter (LM2596) and relay while the other has a LM7805 voltage regulator and TIP122 Transistor.
Buck converter is used to regulate the voltages and provide regulated voltages to the UV lights and water pump, 5V relay is used in between the buck converter and water pump and also connected with the UV lights. Relay is used for the switching purpose and make the system more reliable.
In other PCB design LM7805 is used for the voltage regulation purpose, and TIP122 transistor is used for the switching purpose. Transistor is connected between the voltage regulator and the water pump, also connected with the UV lights. Here both PCB designs are mention below.

12.13. PCB Prototype Layers of LM7805 and TIP122 Transistor design:

Top Layer:

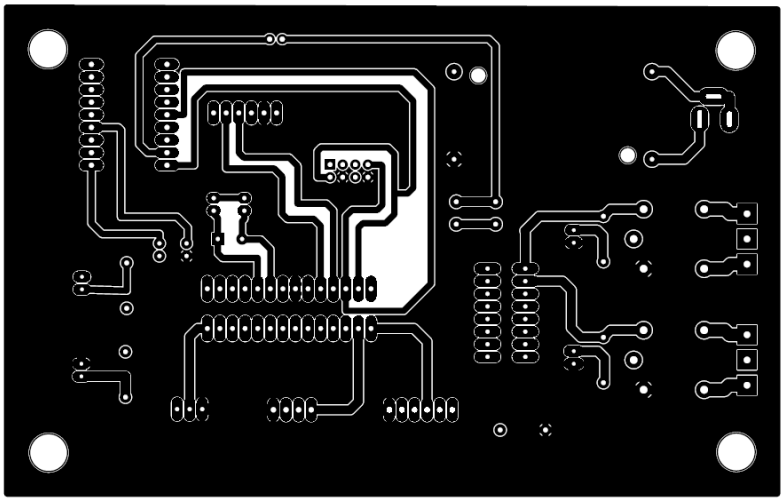


Bottom Layer:

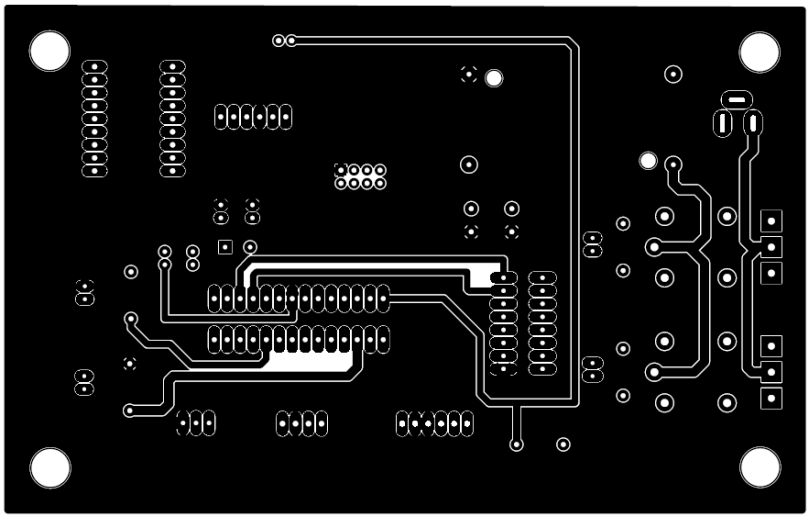


12.14. PCB Prototype Layers of BUCK Converter (2596) and 5V Relay design:

TOP LAYER



Bottom Layer



size	97mm x 65mm

Signal layers	**4**
None signal layers	**10**
Components	**39**
Pads	**130**
Surface Pad	**0**
Plated Through- hole Pads	**130**
Non-plated Through-hole Pads	**0**
Holes	**4**
vias	**0**
Nets	**41/42**
Length of trace	**880.44mm**
Copper Areas	**2**
PCB Board Layers	**2**
Dimensions (Estimated)	**97mm x 65mm**
PCB Quantity	**5**
PCB Thickness	**1.6**
PCB color	**Green**

Surface Finish	**HASL (Lead)**
Copper weight	**1oz**
Manufacturer	**JLCPCB**
PCB Price	**4$**

All schematics that will be used in the team's design project will be attempted to be made with EasyEDA .EasyEDA has the benefit of being an open source project which is great and fully beneficial to the developer community as a whole. Being open source means it is compatible with many various libraries and even supports custom library and footprint designs.

Software	**Cost**	**Features**
EasyEDA	Free	3D Viewer Open Source Easy to Use

13. Part Selection Overview:

The parts that are selected for this project are given in Table 11. The details of each part selected is present in the strategic part selection portion.

Table 11: Parts Selection table

Item	Part#	Manufacturer	Cost(USD)

Pump	-	Walfront	$16.29
Temperature and Humidity Sensor	DHT11		$1.18
UV lamp	QXNA1AA600643	YAM	$8.34
LDR	SNR-3	SKU	$0.05
Crystal Oscillator	HC49S 49S	PUMUDDSY	$0.05
Voltage Regulator	LM7805	vanxy	$0.06
pH sensor	FBM0-AAQ-13688	DONGKER	$37
Switching Transistor	TIP-122	CazenOveyi	$0.01*2(2 pieces)
Programmer	FT232	Usongshine	$1.28
Wi-Fi Module	ESP-01	Adafruit	$3
Soil Moisture Sensor	—	SZEKS	$0.63
Bluetooth Module	HC-05	AITEXM ROBOT	$1.78-2.22
Microcontroller	ATmega328	ATMEL	$1.68

14. Software Design

On the software side of the Indoor Plant Maintenance System we want the end user to be able to constantly monitor that plant's status. This can be done through a WiFi connection or a Bluetooth connection. The user end application will be able to show pH levels, Moisture levels, Temperature/humidity, and light levels as well.

Development with Arduino uno:
For the IPMS we have decided to use an Arduino Uno board in development with the ATmega328 microchip. We made this choice because the Arduino Uno is based off of the ATmega328 as well as coming in the box with one.

To be able to use the Arduino for development we needed to make sure the ATmega chip has the Arduino bootloader so that we can transfer our code onto the board. To do this we used the Arduino as an in-system programmer (ISP) and followed these steps:

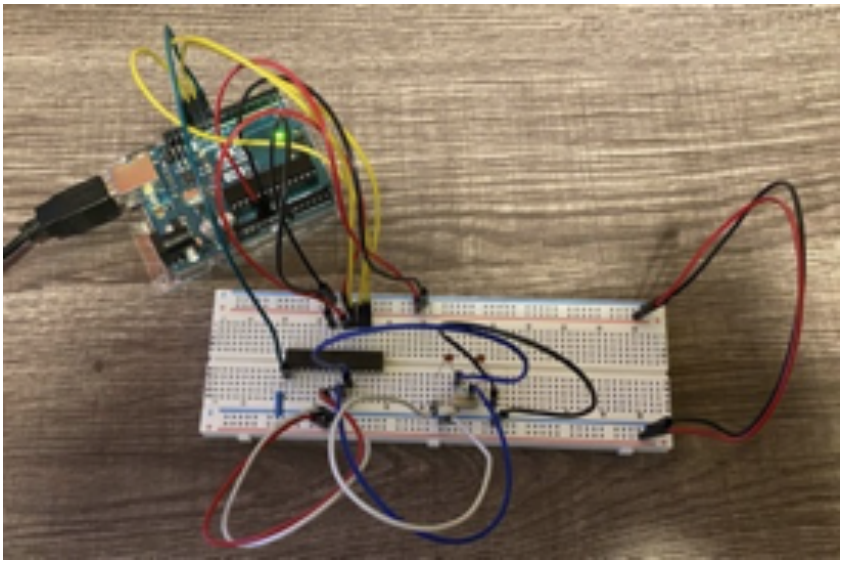
1. Upload the ArduinoISP sketch onto the Arduino uno board. (Select the correct board and port from the tools drop down menu)

2. Wire the circuit as shown in the figure below in order to burn the bootloader using the components listed above.
3. Select “Arduino Duemilanoe” from the board menu and then select “Arduino as ISP” from the tools menu tools>programmer.
4. Burn the bootloader onto the new ATmega328P chip. (Tools>burn bootloader)

The following components were needed for setup:

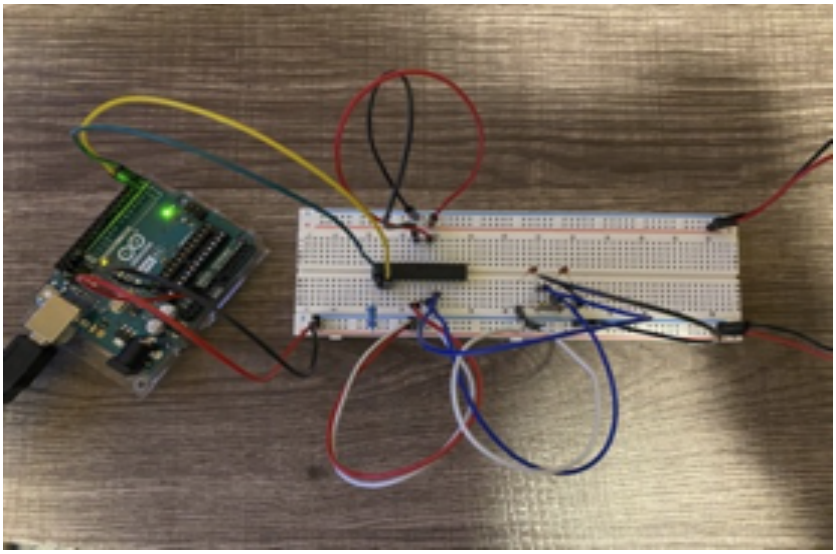
- 16MHz crystal
- 10k resistor
- (2) 20-picofarad capacitors

14.1. Programming the Atmega328P:



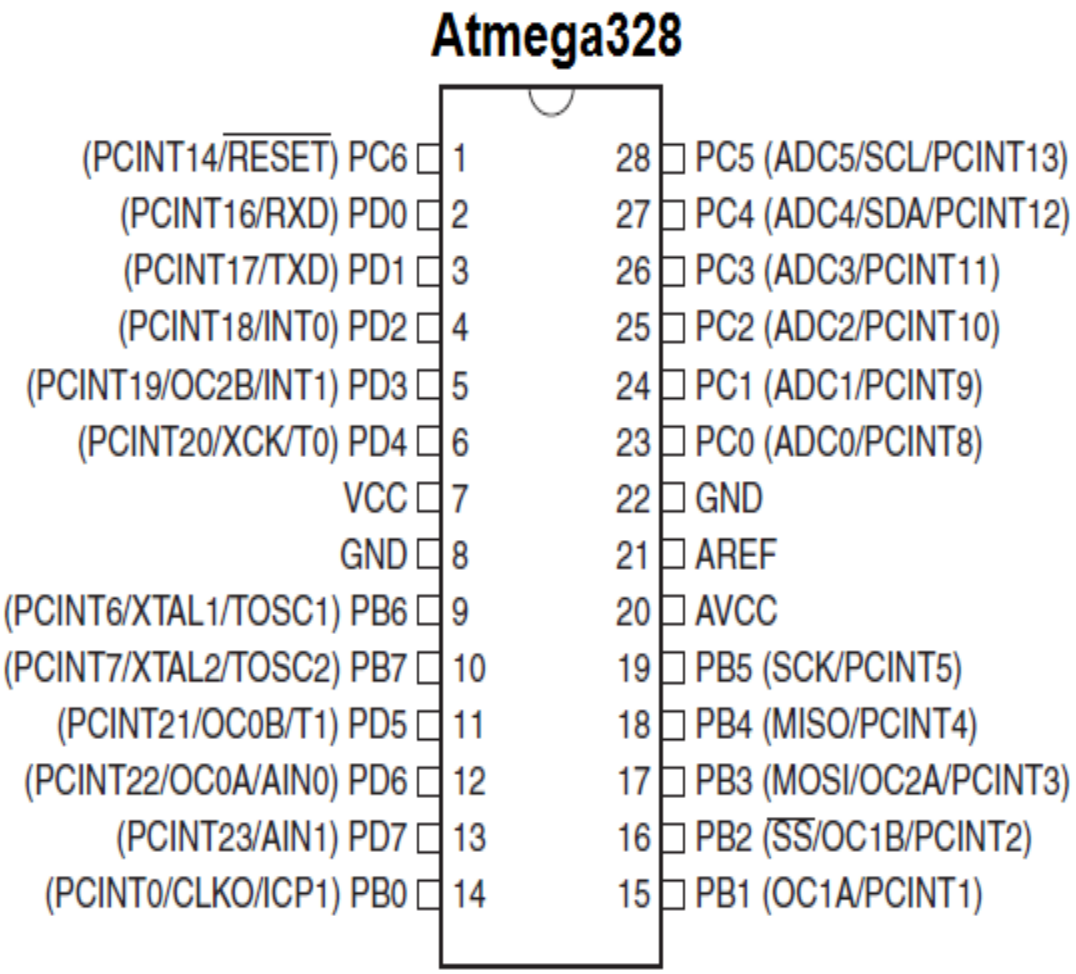
When programming the ATmega328 we upload the code from the Arduino into the ATmega by using the USB-to-serial converter (FTDI) chip on the Arduino board. When we remove the Microcontroller that’s on the Arduino we can then use the Arduino’s FTDI chip to talk the the

external ATmega328P instead. We use the RX, TX, Reset and power pins from the Arduino to program the ATmega328P. We can configure the development circuit as follows:



After uploading the program we want to upload we can then disconnect the Arduino from the circuit and the ATmega328P will run the program on it's own (5V and ground left connected for development only).

The ATmega chip has 28 pins in Total and each chip has can be shown by the following Pin Diagram:



As shown each pin on the Arduino uno can be linked to a pin on the ATmega chip. This allows us to write code to the Atmega Chip to be used as its own stand alone microprocessor to use in our IPMS design.

14.2. Correlation between Arduino and ATmega328P:

For the atmega chip the pins and their functions are listed in the table below. However these pins and pin numbers are NOT the same as the Arduino pin numbers.

Pin Number	Description	Function
1	PC6	Reset
2	PD0	Digital Pin (RX)
3	PD1	Digital Pin (TX)
4	PD2	Digital Pin
5	PD3	Digital Pin (PWM)
6	PD4	Digital Pin
7	Vcc	Positive Voltage (Power)
8	GND	Ground
9	XTAL 1	Crystal Oscillator
10	XTAL 2	Crystal Oscillator
11	PD5	Digital Pin (PWM)
12	PD6	Digital Pin (PWM)
13	PD7	Digital Pin
14	PB0	Digital Pin
15	PB1	Digital Pin (PWM)
16	PB2	Digital Pin (PWM)
17	PB3	Digital Pin (PWM)
18	PB4	Digital Pin
19	PB5	Digital Pin
20	AVCC	Positive voltage for ADC (power)

21	AREF	Reference Voltage
22	GND	Ground
23	PC0	Analog Input
24	PC1	Analog Input
25	PC2	Analog Input
26	PC3	Analog Input
27	PC4	Analog Input
28	PC5	Analog Input

We can observe how the Arduino code can program the pins we want to program on the ATmega with the table that lists the Arduino IDE pin code numbers with the ATmega pin numbers. For example, I may want pin 13 on the ATmega to light an LED but if I code digitalWrite(13,high) then it will not work for pin 13 because pin 13 for Arduino is recognized as pin 19 on ATmega.

ATmega Pin#	**Arduino Pin#**
4	**2**
5	**3**
6	**4**
11	**5**
12	**6**
13	**7**

14	**8**
15	**9**
16	**10**
17	**11**
18	**12**
19	**13**
23	**14**
24	**15**
25	**16**
26	**17**
27	**18**
28	**19**

14.3. Wifi vs Bluetooth Connectivity:

Bluetooth and wifi are both used as wireless technologies for connecting devices to each other and for this Project we wanted the end user to be able to access the application from anywhere.

Range:
Both connections have a good range for the project at hand; however, bluetooth connections are better suited for devices that are within close proximity of one another. For example, wireless headphones, wireless keyboard, wireless mouse etc.

WiFi has an infinite range as a Wifi enabled device would be able to communicate with any other device that can have an internet connection. With this gain in Range there is however a setback in security with Wifi enabled devices. Wifi enabled devices are more prone to security hacks or breaches because they are exposed to much more information traffic.

Speed:
In terms of speed neither selection can get the upper hand because the project will be sharing small amounts of data over a longer period of time. Even though Bluetooth connections are more suitable for small amounts of data being transferred, the increment in speed would be practically negligible because the changes in our data would be gradual over time. In other words our data transfer is not time sensitive.

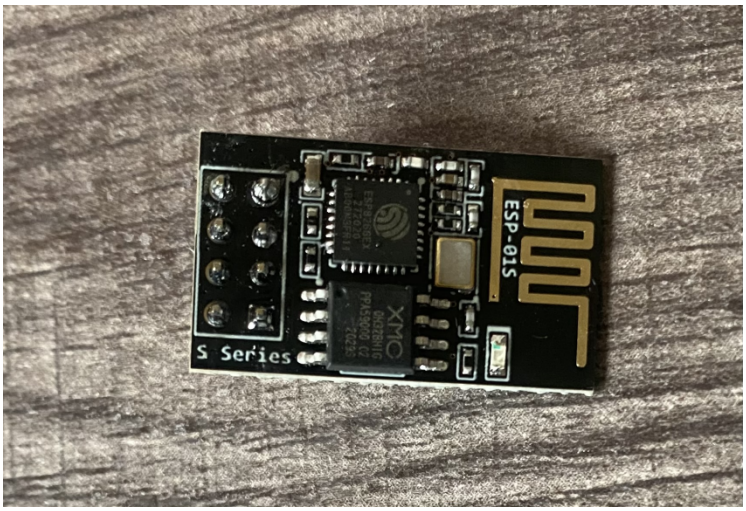
Power:
Bluetooth generally has less power consumption than wifi, however there are many small devices that would be well suited for the low power project design of the IPMS.

14.3.1. WiFi Evaluation:

WiFi will let the user access the IPMS from anywhere that has a WiFi connection. WiFi will also allow the user to access the IPMS information through any device that can access an internet browser. This can be through a phone, tablet or computer. Bluetooth connectivity is not suitable for this project design bc the main purpose is to not be in close proximity of the plant. We want the user to be able to monitor their plant's health from wherever, whenever.

14.4. Software Demonstrations

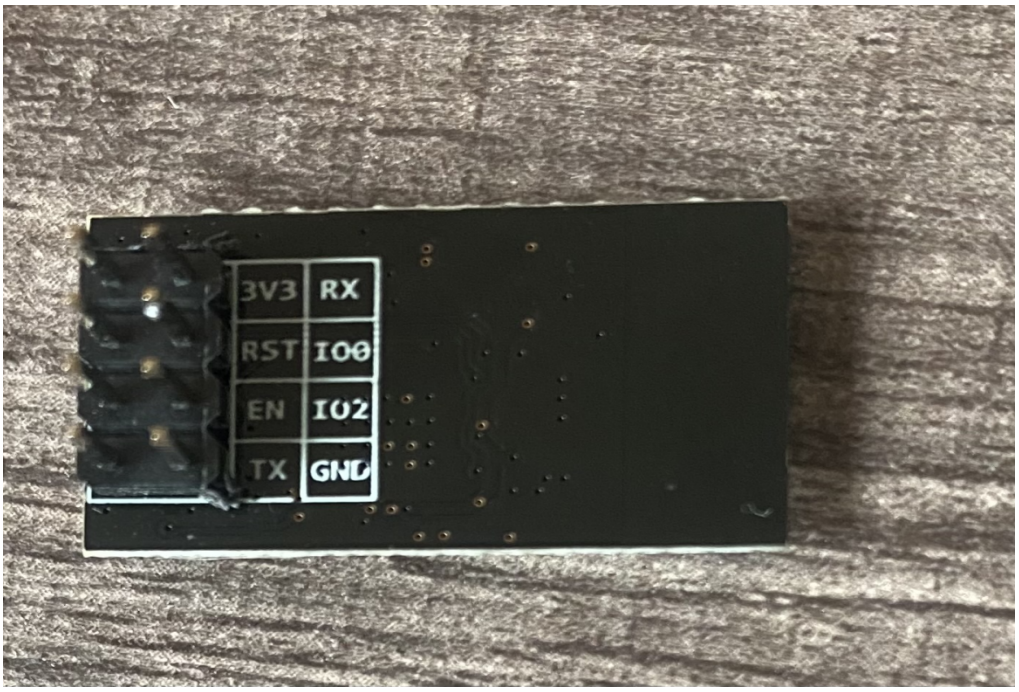
14.4.1. Programming the esp8266 - 01S DEMO:



The esp8266 allows our project to have WiFi capabilities. It will allow us to create a web server where we can then communicate the data we are receiving from the sensors to the microcontroller to the WiFi module and then finally generates an IP address for the web server where it shows up in the users web browser for them to see the plant status from their WiFi enabled device.

The ESP 8266 has 8 Pins that are as follows:

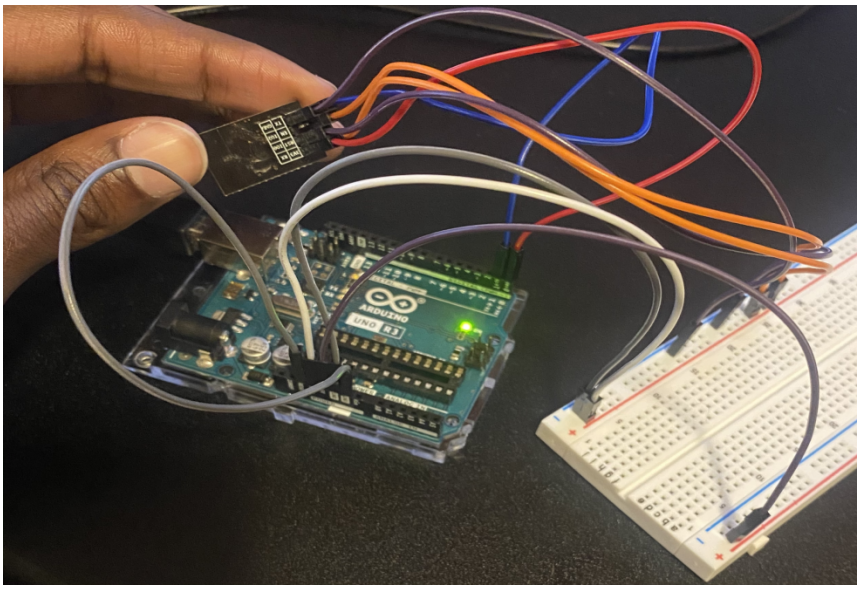
- 3.3Vin
- RST
- EN
- Rx
- Tx
- GPIO0
- GPIO2
- GND



The connections to run the Web server demo are as follows:

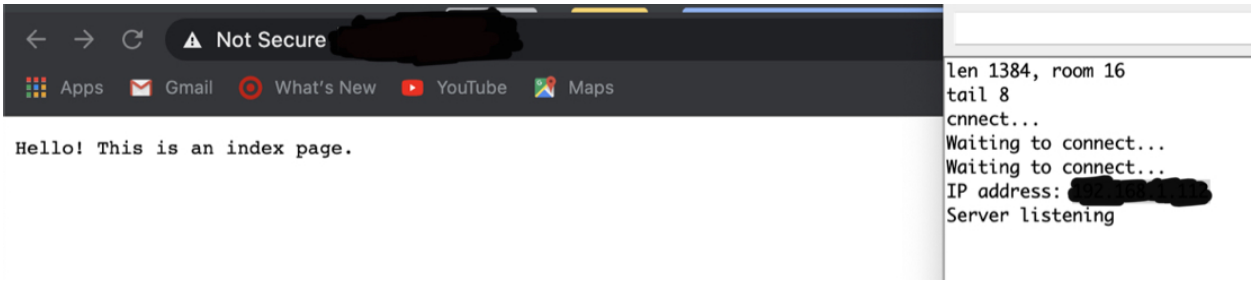
Arduino	ESP
Rx	Rx
Tx	Tx
3.3V	3v3
-	RST
3.3V	EN
GND to set to programming mode	IO0
-	IO2
GND	GND

The assembled circuit was assembled as follows:



14.4.2. Web server with ESP8266WiFi.h & ESP8266WebServer.h Libraries:

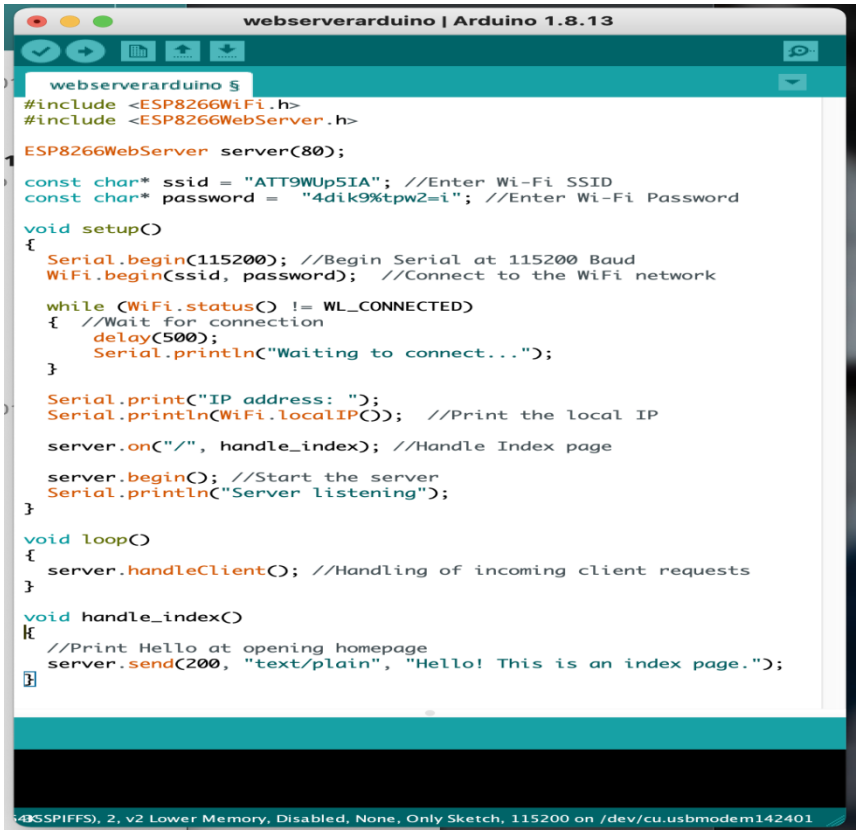
From here the code had to be uploaded to the ESP8266 to set up the Demo WebServer to be displayed as follows. The IP address was hidden for the students privacy:



The code used for the WEb server demo was derived from the arduino Project Hub under "Create ESP8266 Web Server". It is based off of the ESP8266WiFi.h & ESP8266WebServer.h Libraries from which we use the functions: WiFi.status(), WiFi.begin(), Server.begin(), server.on(), server.handleClient(), server.send(), etc.

Once the code is uploaded the esp8266 connects to the given SSID and password and then prints out the IP address to the serial console. From there we can see the web server is up and running by pasting the ip address into a browser and seeing the output as shown above.

14.4.3. Code Snippets from Arduino Demo:



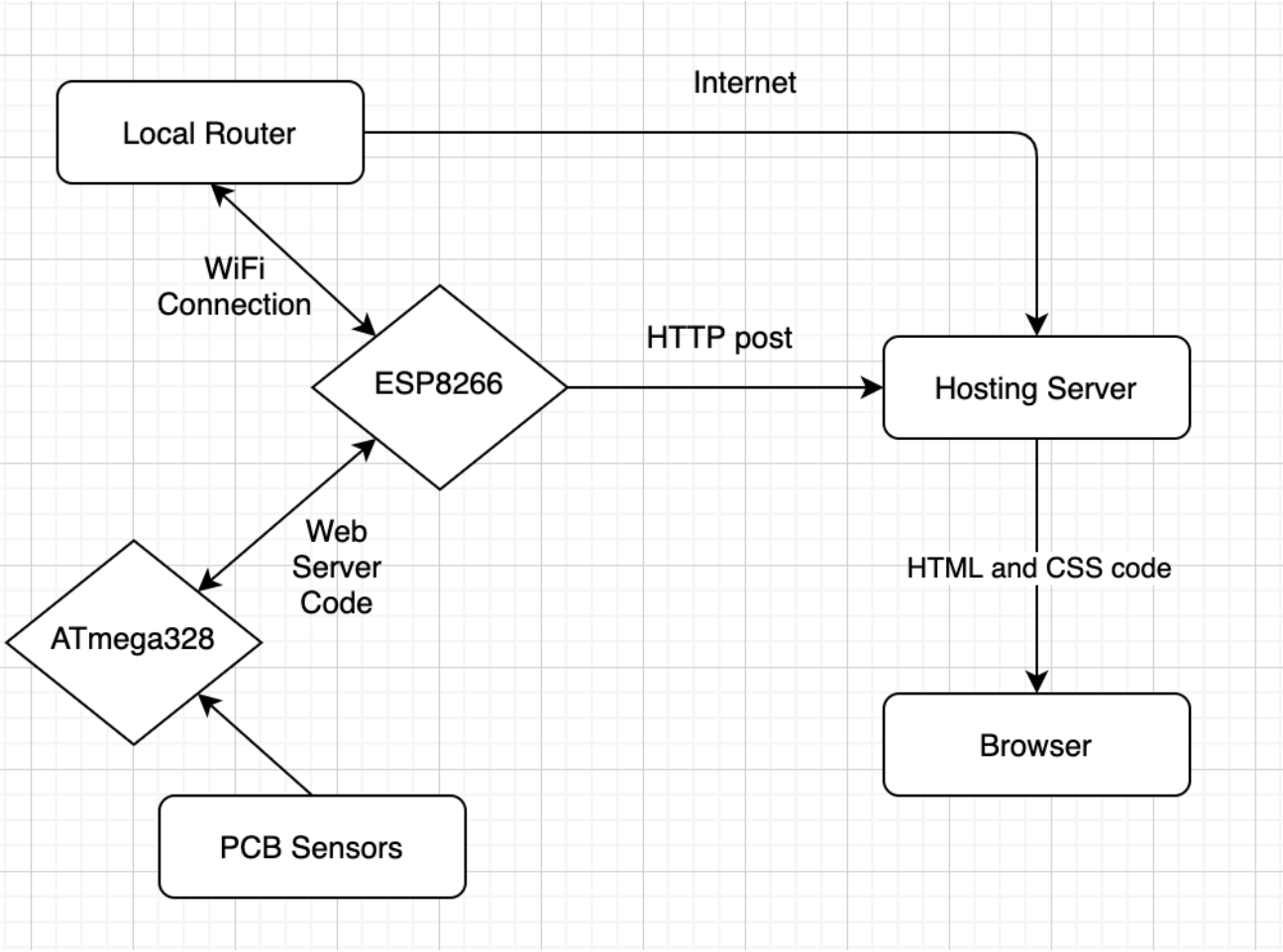
The code snippets of the Demo are shown above. We chose to use elements from this code in our project because it shows how we can program the ESP8266 to create a webserver from where we can develop our IPMS software to work in sync with our printed circuit board.

This Demo code shows how we can connect to any SSID given a certain password. Using the WiFi.begin() function we can connect to the WiFi connection at home. With WiFi.status we can wait for the program to connect to the wifi. Server.on() and Server.begin() allow us to handle the index page and start the server.

Once the web server has been established we can now design the webpage as we see fit. We have decided to use HTML and CSS to design this webpage by using the client.println() function to send our written HTML and CSS code through an HTTP request.

From there this will allow us to visualize the plant's health for the user to use to their benefit. The figure below shows the overall structure of the IPMS software.

14.5. Software Structure:



The software for the IPMS is structured as shown in the figure above. The two main software components are the ATmega328 and the ESP8266. The Atmega is reading information from the PCB sensors and sending them to the ESP8266 WiFi module via the Web server code that we uploaded to the ATmega328.

From the ESP8266 will connect to a local router using a WiFi connection. The ESP8266 then Creates a web server and starts making HTTP requests to the Hosting server. Using HTML code that we will print to the web server, we can create the web page that we can visualize from the web browser.

14.6. Applications

- Display - The Web page will display all information related to the plants overall health including:
    - PH Level
    - Temperature around the Plant
    - Moisture level in the soil of plant
- Control - The Web page will make suggestions based on the current levels of PH, Temperature and soil moisture. The following suggestions can be made:
    - Recommendation: Reduce or Raise the room temp
    - Recommendation: Use water with a higher/lower pH
    - Recommendation: Water the plant (soil moisture low)
- Actions - The web page will have buttons written in HTML and CSS so that the user can carry out certain tasks within the IPMS. Such as:
    - Activate water pump: Water the plant
    - Refresh Display settings and view recent plant health information.

```
client.println("<!DOCTYPE html><html>");
client.println("<head><meta name=\"viewport\" content=\"width=device-width, initial-scale=1\">");
client.println("<link rel=\"icon\" href=\"data:,\">");
// CSS to style the on/off buttons
// Feel free to change the background-color and font-size attributes to fit your preferences
client.println("<style>html { font-family: Helvetica; display: inline-block; margin: 0px auto; text-align: center;}");
client.println(".button { background-color: #195B6A; border: none; color: white; padding: 16px 40px;");
```

The figure above shows snippets of code that can be used to send HTML style text to the web server. This is how we used HTML and CSS code to send over the web server in order to create our webpage. We will use this to style our action buttons and to display our general plant health information.

Each line of code is sent through a client-side HTTP request to the web server. The server carries out the request and sends back the response and the communication is disconnected.

15. Software testing:

15.1. IOT Testing:

For this section of testing we want to make sure all components properly connect with each other and are able to communicate with the microcontroller. This includes the entire Internet

of Things. In this section we will show our testing methods for the Sensors, Microcontroller and ESP8266.

15.2. Components for Testing:

- ATmega328
    - ATmega328 should be able to be programmed using the Arduino uno as an ISP.
- DHT11 Temperature Sensor
    - DHT11 temperature sensors should be able to feed the ATmega328 with data.
- PH Sensor
    - PH sensor should be able to share data to the micro controller.
- Soil Moisture Sensor
    - Moisture Sensor should ba able to feed the ATmega with data from the plant's soil.
- ESP8266
    - WiFi Module should be able to host Web Server and show up in a web browser as valid address.

Test Case #	**Module being Tested**	**Test Function**	**Expected Result**
Test 1	ATmega328	Standalone MicroController (Arduino as ISP)	ATmega328 is able to execute code on its own.
Test 2	DHT Temperature Sensor	Test Connectivity/data sharing with ATmega Microcontroller.	DHT11 Temperature Sensor is able to connect to and share data to the ATmega micro controller
Test 3	PH Sensor	Test Connectivity/data sharing with ATmegaMicrocontroller.	PH Sensor is able to connect to and share data to the ATmegamicro controller
Test 4	Soil Moisture Sensor	Test Connectivity/data sharing with ATmega Microcontroller.	Moisture Sensor is able to connect to and share data to the ATmega micro

			controller
Test 5	ESP8266 Module	Test Connectivity/data sharing with ATmega Microcontroller.	WiFi module is able to connect to Atmega and forward data to the Web server.

15.3. Web server/Web browser Testing:

- WebServer
    - Webserver should be shown in the users browser as a valid address
- HTML
    - Web page should show text from HTML document for the user to see
- Plant Feedback
    - Data from sensors should be displayed on the webpage for the user to see

Test Case #	**Module being Tested**	**Test Function**	**Expected Result**
Test 6	WebServer	Test server accessibility through web browser and IP address.	Browser displays web server page
Test 7	HTML doc	Test if ESP8266 can send HTML text via Web server.	HTML document should be displayed in the user's web browser.
Test 8	Plant Feedback Display	Test if data from sensors is reaching the Web Browser	Webpage should be updated with new data that the

16. Selection of Plants

One of the most critical parts of this project revolves around the selection of plants that we end up designing this project around. Ideally, we plan on having our Indoor Plant Management

System be able to sustain and maintain at least 5 types of houseplants. With this goal, it is critical to pick plants that are all able to survive in the pot that we can design.

Various house plants require a range of different conditions for them to thrive such as lighting, temperature, water, fertilizer, pot size, etc. With all these various ways in which different types of plants can thrive, the easiest way for us to categorize them in terms of this project would be in terms of pot size since that is one of the only variables in the project that we cannot create a range specific to the type of plant and will stay the same for each plant that we program our project for.

With this, we have decided to categorize the potential houseplants we select based on the size of the pot (in diameter) they need in these four different categories: Miniature, Small, Medium, and Large.

16.1. Miniature Houseplants

We have categorized miniature houseplants as a houseplant that requires at max a pot size of 4 inches of diameter. With this, we have selected 5 different common plants of this size that we can potentially design this project around.

- Rose Pincushion Cactuses: Pincushion cacti grow usually to the height of 6 inches and are native to warmer regions of the US. Pincushion cacti thrive in soil that dries out quickly between watering. Temperature should range between 50 to 75 degrees Fahrenheit. Watering should be done sparsely throughout the year.
- Oxalis: Oxalis are a low maintenance plant that does not require much to grow. Oxalis grows best in filtered light and should be watered about once every two weeks. Soil should be moist but not overly wet. This plant works best in temperatures that range from 60 to 70 degrees Fahrenheit.
- Baby Toes: Baby toe plants are native to subtropical deserts and require bright sunlight with a moderate watering cycle. The plant should be grown in temperatures at least 65 degrees Fahrenheit or above.
- Living Stones: These plants grow in inhospitable areas with very limited sources of water and nutrients available to them. The optimal temperature for them would be between 65 to 80 degrees Fahrenheit. Watering for this plant is very seasonal based but overall this plant doesn't require much watering.
- Air Plants: These plants can be grown without soil. Air plants require bright and indirect light ideally on the south or east side. Air plants should be watered every one to two weeks lightly.

16.2. Small Houseplants

We have categorized small houseplants as a houseplant that requires at max a pot size of 6 inches in diameter. With this we have selected 4 different common houseplants that can grow to this range.

- Anthuriums: These types of plants can thrive in all levels of indirect lighting but grow more flowers with more light. Anthurium plants like soil that is intermittently moist and require a watering cycle that is regular. The ideal temperature range for this plant is 65 to 80 degrees Fahrenheit.
- Jade: Jade plants require a sturdy pot since it tends to grow top heavy and often falls over. Jade plants require soil that can drain thoroughly as excessive moisture can lead to root rot easily for them. Jade plants thrive in room temperature between 65 to 75 degrees Fahrenheit. The watering of this plant depends on how quickly the soil dries out (between a week to a month).
- Kalanchoe: Kalanchoe plants grow usually to 12 inches tall and like bright and natural light. Kalanchoe plants need soil that is well drained and requires watering about every two weeks. These plants thrive in room temperatures around 65 to 75 degrees Fahrenheit.
- String of Pearls: String of Pearls are a cascading plant that requires a bright indirect light throughout most of the day. This plant should be kept at 70 to 80 degrees Fahrenheit. This plant should be watered lightly every two weeks as this plant is easy to overwater.

16.3. Medium Houseplants

We have categorized medium houseplants as a houseplant that requires a pot size of 6 to 18 inches of diameter throughout its growth cycle. With this we have selected 5 different common houseplants that can grow within this range.

- Spider Plants: Spider plants require soil that is evenly moisture and prefer moderate to bright indirect sunlight. Its leaves are vulnerable to burning when exposed to direct sunlight. Spider plants should be water occasionally to moderately (every two to three weeks). The ideal temperature for this plant is 55 to 80 degrees Fahrenheit.
- Lucky Bamboo: This plant grows to 1 to 2 feet tall in height. Lucky bamboo prefers moist soil that is well drained with an acidic pH level in the soil. This plant prefers bright

filtered sunlight and should be kept in temperatures that range between 65 to 90 degrees Fahrenheit.

- Christmas Cactus: This plant should be kept in bright, indirect light (preferably east facing light) with a temperature of around 70 degrees Fahrenheit in the daytime and 60 to 65 degrees Fahrenheit in the evening. This plant should be watered every 2-3 weeks or whenever the top third of the soil feels dry.
- Aloe Vera: Aloe vera should receive around 3 to 6 hours of sunlight a day and should be watered every 1 to 2 weeks depending on how dry the soil is. This plant should be kept at around 60 to 75 degrees Fahrenheit indoors.
- Asparagus Fern: This plant grows up to two feet tall and prefers indirect sunlight indoors. The pH level of the soil should be between 6.5 to 6.8. This plant should be kept at temperatures between 55 to 70 degrees Fahrenheit. Asparagus Fern are a thirsty plant so they should be watered weekly to prevent drying.

16.4. Large Houseplants

We have categorized large houseplants as a houseplant that requires a pot size of 12 inches or more in diameter throughout its growth cycle. With this we selected 5 different common houseplants that can grow within this range.

- Peace Lily: Peace Lilies are plants that can either be grown in water or in soil. If grown in water, the soil should be kept moist as this plant can't stand long periods of dryness. This plant thrives in temperatures that range between 60 to 70 degrees Fahrenheit. This plant should be kept in bright indirect light.
- Kentia Palm: Kentia palm plants are low maintenance plants once they are established. Kentia palm plants can grow up to 3-12 feet in height. Kentia palm plants can survive in a wide range of temperatures from 25 to 100 degrees Fahrenheit but should ideally be kept around the 55 degrees Fahrenheit range. The soil pH should be Acidic and should be kept in the shade. This plant should be watered weekly and well hydrated.
- Money Tree: This plant should be kept in medium to bright indirect light but also does well under fluorescent lights. This plant should be watered heavily but sporadically. It should be kept at temperatures between 65 to 80 degrees Fahrenheit.
- Yucca Plant: The overall size of a Yucca plant varies by the specific type of plant you have. This plant prefers a very bright direct or indirect sunlight with a soil pH level of between 5.5 to 7.5. The soil for this plant should be loose and well drained while the plant itself should be watered sporadically. This plant is fairly adaptable in terms of temperature and can survive temperatures from 30 to 100 degrees Fahrenheit.

- Lady Palm: Lady palm plant can grow up to 6 feet tall indoors and thrive under shaded sunlight. The soil pH level should be between neutral and acidic. This plant should be water once every two weeks and should have soil that is well drained.

17. Similar Technologies

With the advancement of various technologies and the never-ending pursuit for convenience, it isn't surprising that there are products already in the market that have similar goals that our project does. Plant maintenance is something that is universally needed throughout the world, whether it be for sustenance or purely decorative purposes.

In this section, we will be looking at some of these other products and highlight some of the features these products use to maintain the plants that they are designed for.

17.1. Supsiah Smart Plant Pot:

Supsiah Smart Plant pot is a self-watering pot stand that has various features included to maintain plants that are planted within it. The main features of this product are as follows: An refillable water tank at the bottom of the pot, a auto alarm system that alerts the user when the pot is short on water (built-in chip that senses capacity), a cotton rope watering method that absorbs water from the water tank at the bottom of the pot and transfers it to the soil, and mesh drain system that drains out excess water from the soil. The pot itself is powered by two AA batteries.

17.2. LUA (Animated Pot):

LUA is an animated smart pot that is currently in development. This pot is unique in that it displays emoticons on alcd screen to describe the current health of the plant that is planted within the pot. There are various emoticons that will display when the plant is thirsty, sick, cold, hot, etc.

This pot achieves this by using four sensors: light, water level, motion, and temperature. This product also features an app that lets the user input the type of plant that they will be planting while also letting them edit the range of temperature, light, and soil moisture level they want the plant to be under while in the pot.

This product is still in development so there are other that may be added in the future, but these are the ones currently listed.

17.3. Parrot Pot:

Parrot Pot is a smart pot that seeks to automatically take off the user's plant for them. Like the Supsiah smart plant pot, this pot features an automated watering system that should ideally last a month at a time without refilling.
This pot also utilizes four embedded sensors to measure the vitals of the plant. These sensors measure sunlight, fertilizer level, temperature and soil moisture. The parrot pot needs to be connected directly to an outlet in order to maintain power.

17.4. AeroGarden:

Unlike the other pots listed already, AeroGarden features products that can maintain multiple different types of plants at the same time. This company has products that can maintain 3 to 24 various plants in one unit.
Each unit implements these main features: Automated LED grow light, alarms/reminders to add fertilizer, water, etc, and an automated system that turns the light on/off.

These four products are a sample of some of the current plant maintenance systems that are already in development or in the market as of today. Some of these products utilize features that we hope to either implement or improve upon when we introduce the final version of our project.

17.5. Plant Potting Materials

Many plants are very fickle when it comes to the conditions it needs to survive and thrive. Sunlight, soil moisture, fertilizer, temperature, and are some of the few variables that can determine whether or not a plant will grow successfully. When it comes to indoor plants, the material of the pot can also be an important factor also.

Various pot materials can lead to different growing conditions when it comes to raising plants. The way you water a houseplant that is planted in a clay pot is different from the way you would water a plant that is in a metal pot. This section of the paper will explore the

multiple types of material we can potentially use to create the housing unit (pot) for this project while also listing the pros and cons of using each type of material.

Terracotta:

Terracotta pots are manufactured from a variety of clay-based materials. Normal terracotta pots are usually unglazed and semi-porous which allows for air and water to barely pass through the pot. Terracotta pots usually feature a single drainage hole at the base of the pot.

Pros:

- Typically inexpensive
- Good for plants that require drier, well drained soil
- Pots are sturdier than other typical pots which allows for the user to plant taller plants without the fear of it tipping over.

Cons:

- Soil dries out faster
- Heavy when filled with soil (hard to move around)
- Material is very brittle and is prone to breaks
- Material retains heat for long periods of time

Ceramic:

Ceramic pots are manufactured from earthen materials that are very dense and non-porous in comparison to terracotta pots. These pots are glazed on both the outside and inside.

Pros:

- Very durable and can last extended periods of time
- Can retain soil moisture for a longer period than terracotta pots
- Pots are sturdy

Cons:

- Heavy when filled with soil
- Can be expensive

Plastic:

Pros:

- Least expensive of all pot materials
- Lightweight in nature
- Durable
- Soil retains moisture

Cons:

- Extended amount of sunlight can lead to the plastic becoming brittle
- Chemicals can leak into soil
- Non-porous material can lead to overwatering.

Fiberglass:

Fiberglass pots are made from combining fiberglass fibers with resin. Fiberglass comes in an endless variety of shapes and sizes and is non-porous.

Pros:

- Durable
- Lightweight
- Soil retains moisture

Cons:

- Expensive
- Outside of the pot can fray

Metal:

Pros:

- Durable
- Metals items can be repurposed to be plant containers
- Soil retains moisture

Cons:

- Metal can rust
- Heavy when filled with soil
- Retains heat when exposed to sunlight

Wood:

Pros:

- Can easily be created at home
- Inexpensive

Cons:

- Wood retains water and can decay
- Soil will dry out faster (porous material)
- Wood needs to be resealed periodically to prolong life

	Cheap	Good for dry soil	Good for moist soil	Sturdy	Heat retainment	Durability
Terracotta	X	X		X	X	
Ceramic			X	X		X
Plastic	X		X			
Fiberglass			X			X
Metal			X	X	X	X
Wood	X	X		X		

Given all of this information about the pros and cons of each type of material, it Is important for us to take all of this information and use it to decide which type of material is most important for our housing unit and plan accordingly. Through simple analysis we would likely choose a material that is non-porous so that water doesn't leak through to other components of the IPMS that wasn't meant to retain water. We would also likely choose a material that is very durable so that the IPMS unit can last a long time and won't have to oftentimes be replaced by the user.

18. WaterProofing

Water and electronics don't typically mix well which is why it is critical that we make sure that the electrical co,mponents of this project are waterproofed just in case water from either the water tank installed onto the IPMS or simply from watering the plant itself leaks into them.

It is critical to make sure that electronics involved in the IPMS are waterproofed just in case this situation does occur as it could destroy the project itself. Luckily, this is a common problem among engineers when it comes to mixing water with electronics. With that, there are currently multiple ways in which we can tackle this problem and find a solution to it.

In this section, we will go over the various known ways to waterproof our electronics(PCBs and connections) and list the benefits and disadvantages of using each method to waterproof the electrical components of our project.

18.1. PCB Waterproof:

There are a bunch of different ways to waterproof a pcb board with the solutions ranging from a cheap to expensive fix and also permanent to non-permanent. Here we will look at some of these methods.

- Clear Nail Varnish:
  - Clear nail varnish is a very cheap method that can be used to waterproof your PCB
  - This method prevents both dust and moisture from collecting onto your PCB
  - Nail varnish sets pretty quickly which is why you have to make sure everything is connected correctly and works before using this method because there is no going back once you begin to apply the varnish
  - Coating from this varnish is very hard and rigid
  - Coating can be difficult to apply evenly which can lead to build up on certain areas of the PCB

- High temperatures can cause the varnish on the PCB to peel away

- Special PCB Varnish:
  - This varnish goes by different names based on the company is created by but it is essentially varnish that is made specifically for PCBs
  - This varnish can be fairly expensive based on the market/company that you purchase the varnish from
  - This varnish is spray which allows for the coating to be evenly distributed throughout the PCB
  - Once this varnish sets, the coating remains semi-flexible which allows for the PCB to be slightly bent without the fear of cracking on the coating.
  - Varnish is transparent once set

- UV Curable Soldermask:
  - This method is very inexpensive
  - This substance can survive extreme temperatures
  - Once applied to the board, you only need to shine a UV flashlight to the substance for 30 seconds in order for it to harden and provide protective layer
  - This substance is very liquid so it only works on flat surfaces which makes it hard to coat an entire PCB with

- Conformal Coating
  - Conformal coating is the industry standard way for waterproofing electronics and PCBs.
  - This method can be very expensive since conformal coating spray can be sold in bulk depending on the amount needed
  - Protective against extreme temperatures

- Waterproof PCB enclosure
  - This is one of the simpler ways to waterproof a PCB which is by simply enclosing it within a waterproofed box/enclosure to protect it from water damage.
  - It can be tricky to fit all of the various wires and components that are connected to the PCB within the enclosure, especially if those components are supposed to travel beyond those areas.

	Price	Temperature	Coating
Clear Nail Varnish	Very Cheap	Heat sensitive	Liquid state initially but sets in a hard and rigid state
PCB Varnish	Fairly Expensive	Heat Resistant	Spray on and flexible when it sets
UV Curable	Cheap	Extreme Temperature Resistant	Liquid state initially and sets with a UV light
Conformal Coating	Expensive	Extreme Temperature Resistant	Spray on

18.2. Waterproofing Connections

Waterproofing the electrical connections to the PCB can be a lot simpler than waterproofing the PCB as a whole. This section will explore three common products used to waterproof these sections. In general, everyone of these methods are relatively inexpensive compared to the potential cost of waterproofing a PCB.

- Liquid Electrical tape
  - o This is a rubber fluid compound that can prevent moisture from being able to penetrate or enter a certain place.
  - o This compound can survive extreme temperatures
  - o This compound can be applied using a brush so that the user can create the form in which is holds according to their needs
  - o Dries very quickly
  - o Substance is volatile to fire
  - o Inexpensive

- Silicone Tape

- Electrical tape typically used to protect leaks
- Can be wrapped around electrical connections to protect them
- Non-permanent solution as it can be taken on and off at will
- This is seen more as temporary solution as the tape can give out as time goes on
- Inexpensive

- Adhesive Heat Shrink Tube
  - Shrink tube that can form around most electrical connections when heat is applied to the tube
  - Protects against moisture and dust build up
  - Cannot withstand extreme high temperatures
  - Inexpensive

	Price	Temperature	Coating	Permanence
Liquid Electrical Tape	Cheap	Extreme Temperature Resistant	Rubber fluid compound that dries very quickly	Long-lasting solution to protect
Silicone Tape	Cheap	Heat resistant	Tape	Temporary solution to protect
Adhesive Shrink Tube	Cheap	Heat sensitive	Tube that forms around substance when heat is applied	Long-lasting solution to protect

Appendix A - References

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